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PLOWSHARE

SC-RR-68-449
September 1968

CRATER FORMED BY DETONATING A ROW OF CHARGES BENEATH A RIDGE

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Sandia Laboratories

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L. J. Vortman, 9111
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Albuquerque, New Mexico

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ABSTRACT

A row of 64-pound charges was placed 7 feet below the top of a nearly four-foot high ridge formed by the arc of a circle with its center at the row axis. The row of charges was 5 feet below the original ground surface. The volume of the resulting crater was 86 percent and 60 percent greater than craters from rows 5 feet and 7 feet deep, respectively, below level terrain. Even if one disregards the portion of the ridge above the level-terrain plane (providing an effective burial depth of 5 feet), directed blasting still provides an increase of 32 percent in volume excavated over a row buried 5 feet below level terrain. More material is ejected laterally, hence less falls back into the crater than if the ground had been level. Vertical displacement of the surface over the charges is comparable during the first 12 milliseconds, but thereafter is greater as a result of the interaction of charges in the row.

m

Summary

The concepts of directed blast were used to examine results of detonating a row of charges beneath a ridge. Five 64-pound charges were placed 8 feet apart and 7 feet beneath a ridge whose cross section formed an arc with the charge at its center. Crater dimensions were obtained, ejecta distributed was measured, and surface motion was observed. In the center portion of the crater, the crater volume per charge was between 60 and 86 percent more than that produced by a comparable row of charges detonated beneath level terrain. If one disregards the portion of the ridge above the level-terrain plane (making an effective burial depth of 5 feet), directed blasting still provides an increase of 32 percent in volume excavated over a row buried 5 feet below level terrain. The amount of ejecta, measured perpendicular to the axis of the row, was greater at the larger distances than would have been expected from a comparable row detonated beneath level terrain. Vertical displacement as observed off the end of the row was compared with vertical displacement of single charges in NTS alluvium and in NTS playa. The displacements were comparable during the first 12 milliseconds and thereafter the displacements from the row exceeded those of single charges as a result of the interaction between charges in the row.

CRATER FORMED BY DETONATING A ROW OF CHARGES BENEATH A RIDGE

Introduction and Background

Pokrovski[1] introduced the concept of directed blasting in which ejecta is directed in a preferred direction by preshaping the ground surface. The ejecta velocity is inversely proportional to the distance from the charge to the free surface. The ejecta is expelled radially away from the charge.

In the excavation of a sea-level canal using nuclear explosives there may be some choice in alignment, allowing rows of charges to follow ridges or valleys. The question has been raised whether the concepts of directed blasting can be used to advantage by choosing terrain which would permit more material to be ejected at low angles, minimizing fallback and maximizing crater dimensions. Where a row of charges is detonated immediately below the bottom of a valley, most of the material goes straight up and then falls back into the crater, resulting in a minimum amount of excavation. This is illustrated for a single charge by Figures 1 and 2, which are taken from Reference 1.

Where a row of charges is detonated immediately below a ridge, the effect is precisely the opposite; more material is ejected laterally at lower angles and does not fall back into the crater. Some work on directed blasting done by Vesic[2] has formed the basis for the design of the experiment described herein.

The purpose of this experiment was to determine the effectiveness of firing a row of charges beneath a ridge as compared with firing a row beneath level terrain.

Experiment Design

An earlier experiment[3] resulted in parallel-row-charge craters with a different spacing between each pair of craters. Ballistic collision of ejecta from two simultaneously detonated rows of 8-pound charges formed a ridge between the craters. The ridge between two sets of row-charge craters with a spacing of 17.5 feet was chosen for this experiment. The upper portion of the ridge was modified so that its profile was the arc of a circle with a 7-foot radius. The charges were placed 7 feet below the top of the ridge, hence at the center of the arc. This depth is slightly greater than the optimum 6-foot burial depth used in level terrain for 64-pound charges.

The charges were 64-pound spheres of cast TNT detonated at the center of the charge. Five charges were used, spaced 8 feet apart. This is the spacing which, for the Albuquerque alluvium, maximizes

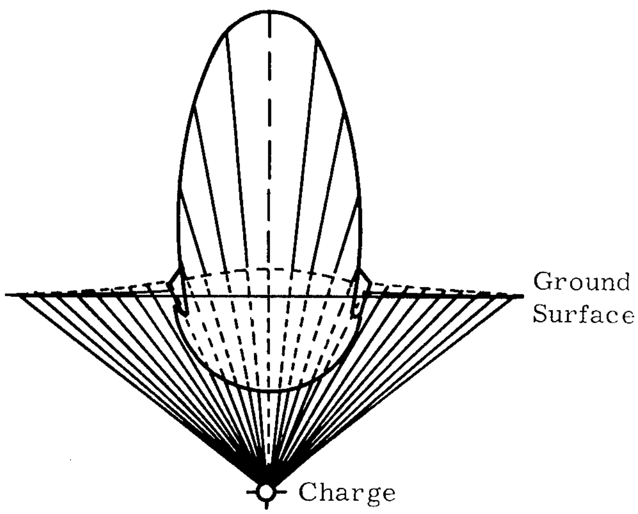


Figure 1. Boundary of velocity field of ejecta when charge is detonated below an existing hemispherical excavation

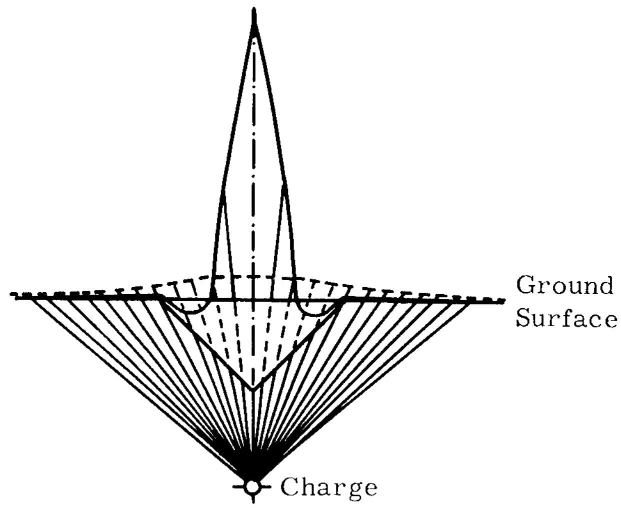


Figure 2. Boundary of velocity field of ejecta when charge is detonated below an existing conical excavation

crater dimensions with a 6-foot burial depth beneath level terrain. The fact that the terrain was not level was taken as reason for a slightly larger burial depth. Figure 3 is a preshot photograph of the experiment area. Note that the ridge was much larger than the craters on either side.

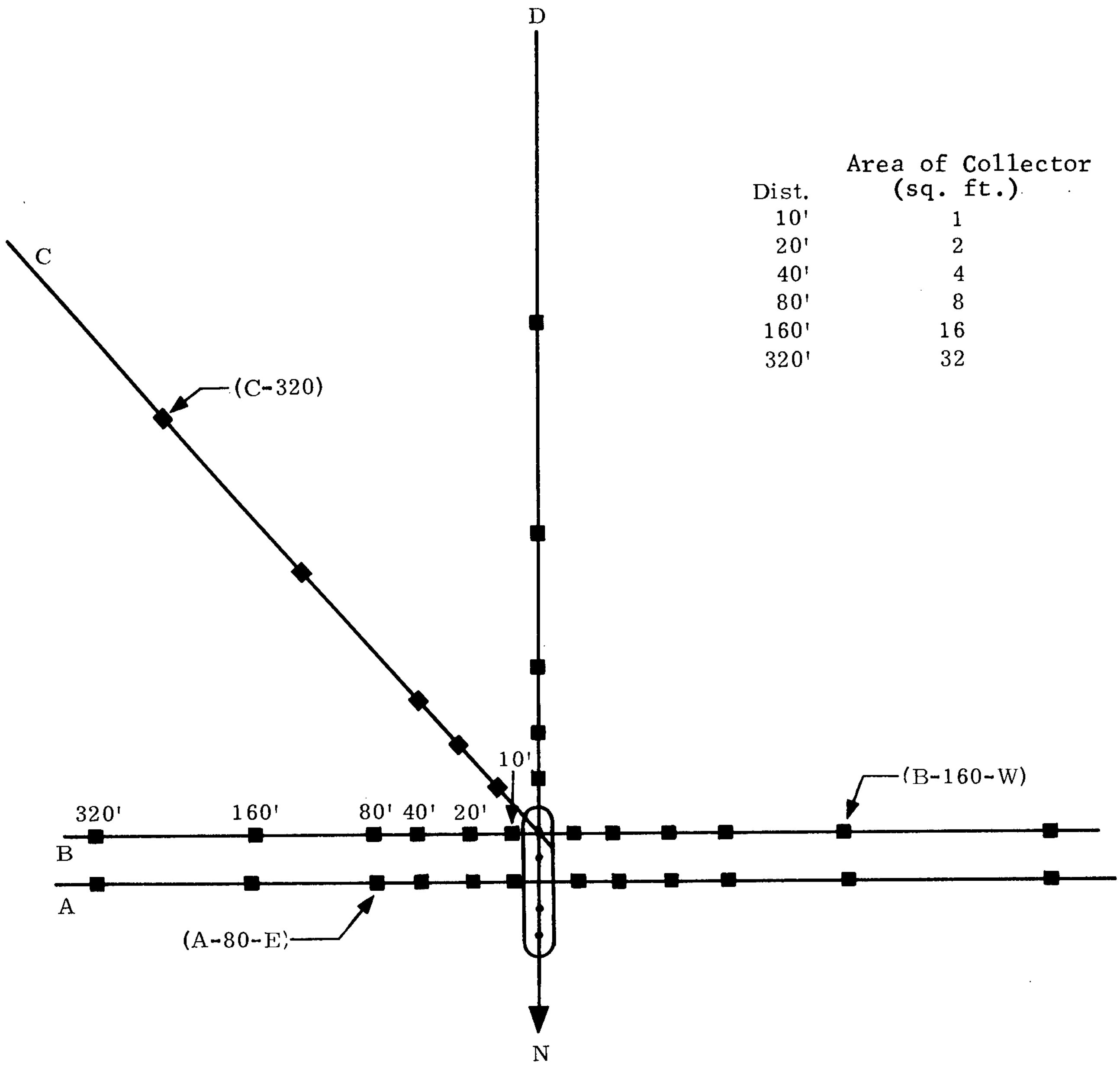
To facilitate comparison with ejecta from row charge craters in level terrain, ejecta collections were made according to the layout illustrated in Figure 4.

Motion picture coverage was obtained from the cameras listed in Table I. Cameras were located 600 feet south of the middle of the row. Camera targets were placed 20 and 40 feet on each side of the axis of the row, at the middle of the ridge.

TABLE I

Camera	Speed (fps)	Lens (in.)	Film	Timing Cycles	Field of View Height (ft)	Field of View Width (ft)
35 mm 1/2 frame	2500	10	4X	1000	21	58
35 mm 1/2 frame	2500	6	4X	1000	36	93
35 mm full frame	100	2	Plus X	100	216	290
35 mm full frame	1500	2	D-200	1000	216	290

Figure 3. Hemisphere-profile ridge before detonation



Dist.	Area of Collector (sq. ft.)
10'	1
20'	2
40'	4
80'	8
160'	16
320'	32

Figure 4. Pick ax earth dam sample collection pads

Results

The shot was fired at 11:10 a.m. November 18, 1967. The wind was west, at 5 m.p.h.

Crater -- The crater is shown in Figure 5 and the topographic map in Figure 6. Crater dimensions are compared in Table II with craters from comparable 7-charge rows, one with a 5-ft and one with a 7-ft burial depth, but in level terrain.[4] Average crater depth is more than 40 percent deeper than for charges in level terrain, based on the intercept with the original ground surface.

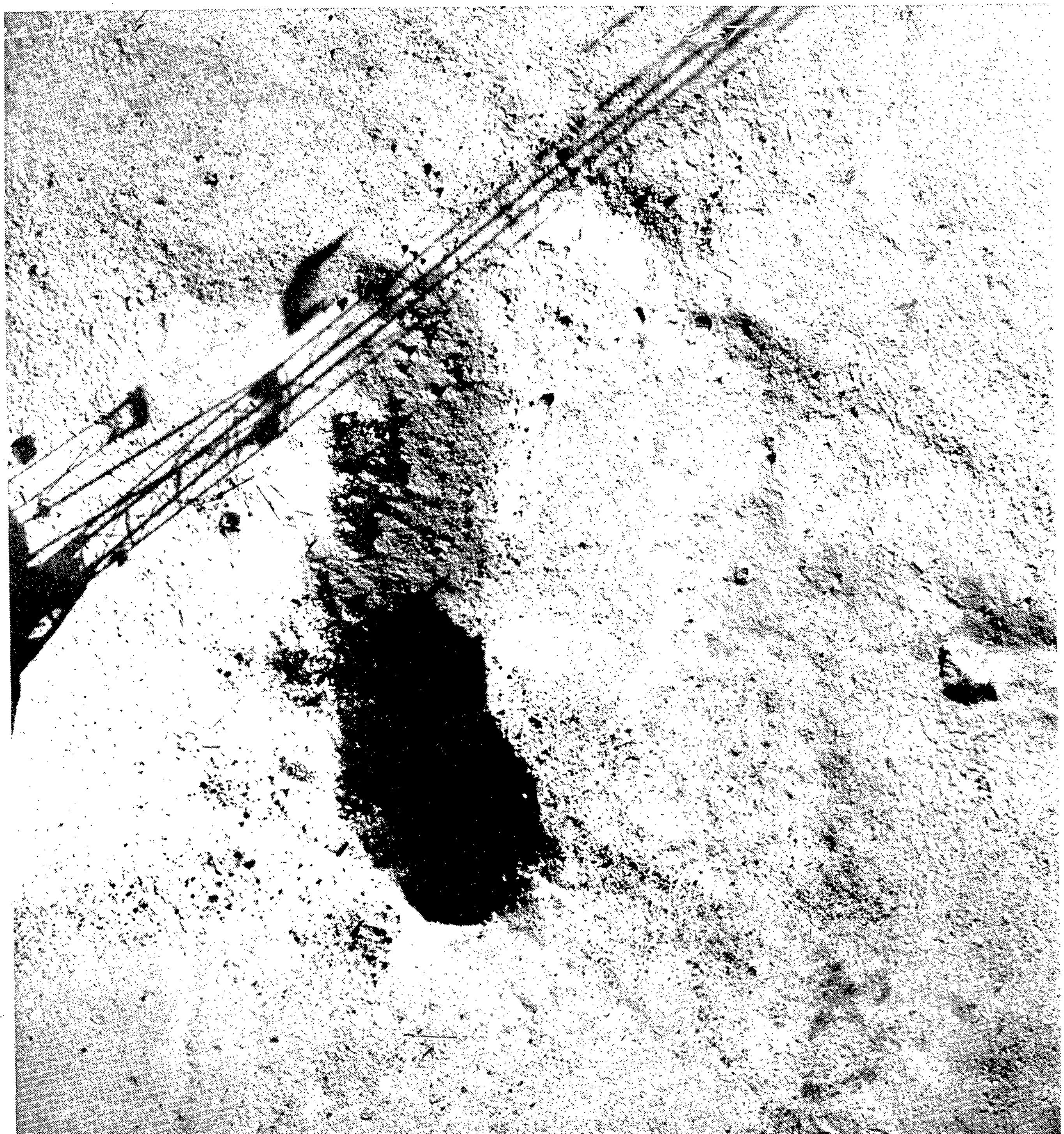


Figure 5. Ridge crater after detonation

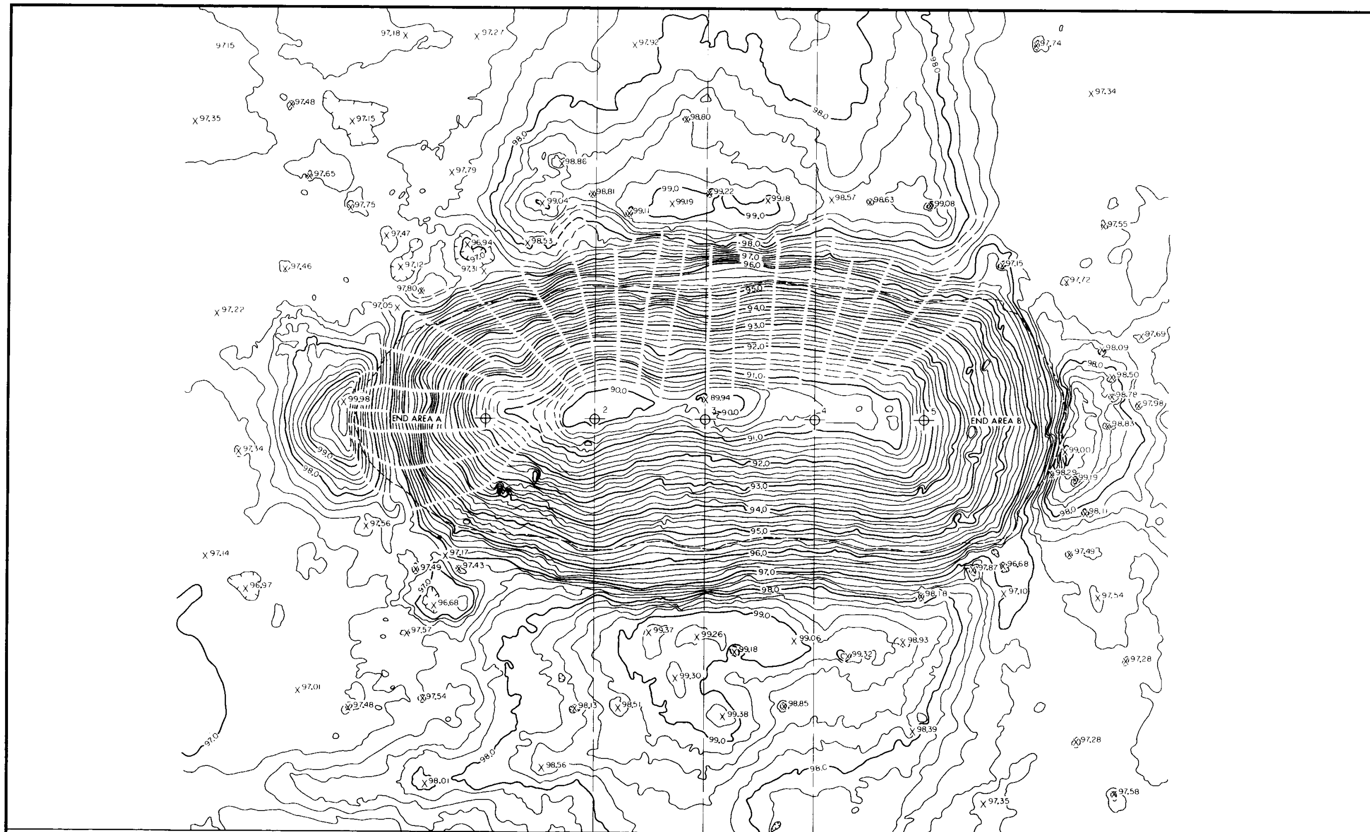
TABLE II

	Ridge	Level Terrain	
	Five 64-lb charges 7 ft deep	Seven 64-lb charges 5 ft deep	Seven 64-lb charges 7 ft deep
Total volume (cu ft)	3546	2808	3158
Per charge (cu ft)	709	401	451
Volume between end charges (cu ft)	2900	2390	2710
Per charge (cu ft)	725	398	452
Volume between second charges from each end (cu ft)	1496	1607	1867
Per charge (cu ft)	748	402	467
Average width between end charges based on level ground (ft)	-	18.29	19.7
Based on preshot terrain (ft)	18.44		
Average depth between end charges:			
Below level ground (ft)	6.46	4.53	4.59
Below top of ridge (ft)	8.44	-	-

Average crater width cannot be compared on the same basis. The profiles in Figure 7 show that the intercept of the final crater of the ridge shot is nearly 25 percent greater at the level-terrain line than at the intercept with the preshot profile. Since Table II shows the crater width at the preshot profile intercept to be comparable with ground-level crater width for shots in level ground, it is clear that crater width has also been enhanced by detonating charges beneath the ridge.

Volume considerations illustrate in a most spectacular way the advantages of directed blasting. Comparisons are best made on the basis of volumes measured between second charges from each end. The increasing volume per charge as the center of the crater is approached evidences less two-dimensionality for the 5-charge rows than for the 7-charge rows. Based on the center portion, directed blasting provided 86 percent more volume per charge than the row buried 5 feet beneath level terrain and 60 percent more than that buried 7 feet. If one disregards the portion of the ridge above the level terrain plane (making an effective burial depth of 5 feet) directed blasting still provides an increase of 32 percent in volume excavated over a row buried 5 feet below level terrain.

Ejecta -- The results of the ejecta collection are listed in Table III. An error developed in the collections along the A lines due to the collected ejecta having been mislabeled and attributed to the wrong stations. Fortunately, it was possible at the two 20-foot and 40-foot stations to check the information against the ejecta thickness



CRATER FORMED BY

5-64 lb. CHARGES SPACED 8 ft. APART

BURIED 7 ft. FROM TOP OF MOUND

NOVEMBER 1967

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

LIMBAUGH ENGINEERS, INC.

Figure 6

CRATER VOLUME

Charges	1-5	2,899.88 cu. ft.
Charges	2-4	1,496.20 cu. ft.
End Area	A	262.34 cu. ft.
End Area	B	383.37 cu. ft.

AVERAGE CRATER DEPTH
(BASED ON INTERPOLATED ORIGINAL GROUND)

Charges	1-5	6.46'
Charges	2-4	6.67'

AVERAGE CRATER DEPTH
(BASED ON TOP OF MOUND)

Charges	1-5	8.44'
Charges	2-4	8.61'

AVERAGE CRATER WIDTH
(BASED ON INTERCEPT SHOWN)

Charges	1-5	18.44'
Charges	2-4	18.81'

DEPTHS BELOW INTERPOLATED ORIGINAL GROUND

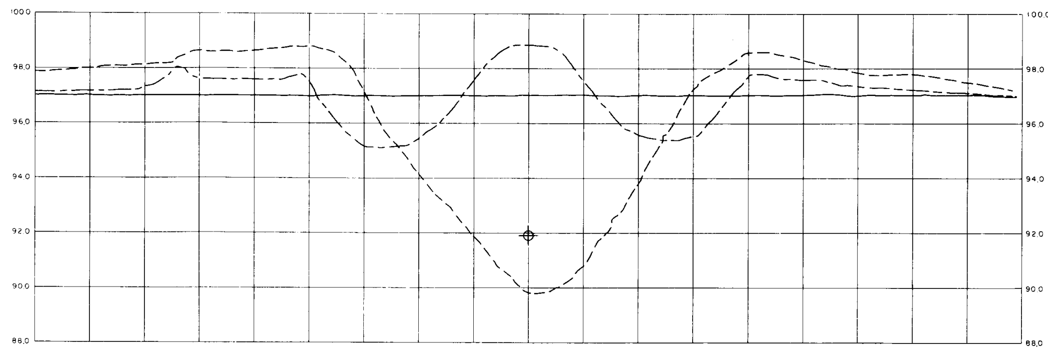
Charge	Depth
1	5.51'
2	7.05'
3	6.76'
4	6.34'
5	5.17'

DEPTHS BELOW TOP OF MOUND

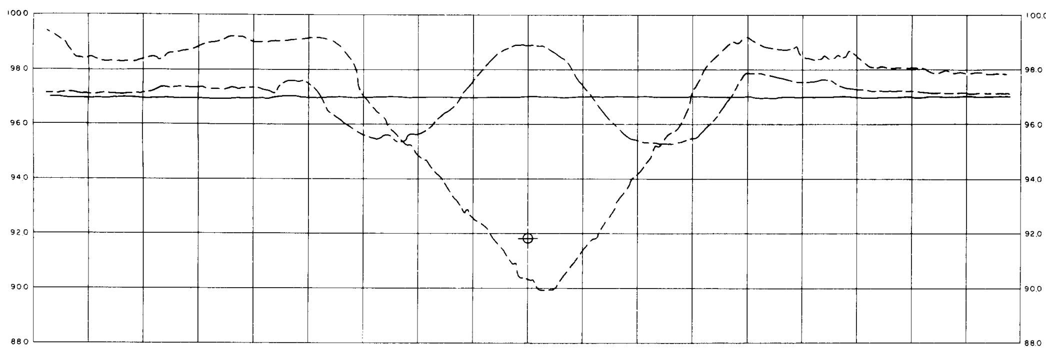
Charge	Depth
1	7.44'
2	8.96'
3	8.67'
4	8.37'
5	7.22'

LEGEND

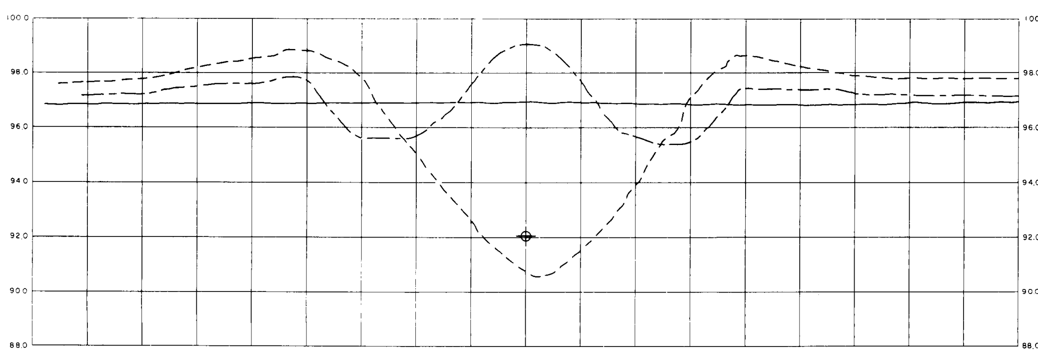
CHARGE LOCATIONS
INTERCEPT
PROFILE LINES



CROSS SECTION THROUGH CHARGE No. 2



CROSS SECTION THROUGH CHARGE No. 3



CROSS SECTION THROUGH CHARGE No. 4

CROSS SECTIONS THROUGH CRATER FORMED BY

5-64 lb. CHARGES SPACED 8 ft. APART

BURIED 7 ft. FROM TOP OF MOUND

NOVEMBER 1967

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

Horizontal Scale 0 2 4 8 12 16

Vertical Scale 0 1 2 4 6 8

LEGEND

CHARGE LOCATION ⌖

INTERPOLATED ORIGINAL GROUND

PRE SHOT GROUND

POST SHOT GROUND

Figure 7

LIMBAUGH ENGINEERS, INC.

CONSULTING ENGINEERS and PHOTOGRAMMETRISTS

TABLE III

Ejecta Collected

Station	Weight (lb)	Area (ft^2)	Density (lb/ft^2)
A-10-E (destroyed)			
A-20-E	46.44	2	23.22
A-40-E	622.81	4	155.7
A-80-E	238.44	8	29.8
A-160-E	2.19	16	0.137
A-320-E	0.19	32	
A-10-E (destroyed)			
A-20-W	77.5	2	36.75
A-40-W	63.5	4	15.88
A-80-W	509.0	8	63.6
A-160-W	2.38	16	0.149
B-10-E (destroyed)			
B-20-E	44.94	2	22.47
B-40-E	20.13	4	5.03
B-80-E	9.13	8	1.14
B-160-E	0.75	16	0.047
B-320-E	0.06	32	0.0019
B-10-W (destroyed)			
B-20-W	22.75	2	11.38
B-40-W	7.69	4	1.92
B-80-W	13.25	8	1.66
B-160-W	1.25	16	0.078
B-320-W			
C-10- (destroyed)			
C-20	7.0	2	3.5
C-40	1.13	4	0.28
C-80	1.25	8	0.156
C-160	0.25	16	0.0156
C-320			
D-10 (destroyed)			
D-20	4.50	2	2.25
D-40	1.50	4	0.38
D-80	0.19	8	0.0238
D-160	0.03	16	0.0019
D-320			

shown in the topographic maps, and that information has been added to Figure 8. The topographic map gives no reason to challenge the data listed in Table III for the other stations.

No ejecta collections have been made for rows of 64-pound charges in level terrain in the Albuquerque alluvium. Information is available for single 256-pound charges and for a row of five 256-pound charges[5].

Information from those experiments has been extrapolated to cover a single 64-pound charge and a row of five 64-pound charges by scaling distance and ejecta density by the cube root of the charge weight.

Ejecta perpendicular to the center line is greater at large distances than would be expected from five 64-pound charges (Figure 8) detonated beneath level terrain. In fact, it is nearly as large as ejecta from a row of five 256-pound charges. Perpendicular to the row at the end charge, the ejecta distribution is less at closer ranges than would be expected from five 64-pound charges in level terrain based on the scaling described above. It is more nearly comparable to ejecta distributed by a single 256-pound charge (Figure 9).

At an angle of 45 degrees off one end charge, the ejecta distribution was as predicted by scaling from five 256-pound charges to five 64-pound charges (Figure 10). Directly off one end of the row, the ejecta distribution was less than predicted for a single 64-pound charge by scaling results of single 256-pound charges (Figure 11). To some extent ejecta off the end may have been reduced by shielding provided by the end of the ridge, since the length of the ridge was greater than that of the crater.

Selected frames from motion pictures of ejecta from the ridge shot are shown in Appendix A. Figure A-9 is a photo of ejecta from a row of charges beneath level terrain. (Although these were 256-pound charges, the picture corresponds to about 144 seconds of the detonation from a row of 64-pound charges.) A comparison of the motion-picture frames with Figure A-9 illustrates how much greater the horizontal ejecta component is in the ridge shot.

<u>Photography of Surface Motion and Ejecta</u> -- Six photographic targets consisting of cubical plywood boxes with 1-sq-ft surfaces were placed across the mound at its midlength. These targets provided an unsatisfactory measure of surface motion because they were obscured by the rising mound. The obscuration may have occurred either because the near end of the ridge rose ahead of the midpoint or, if the mound rose evenly, because of the low camera angle. It is unlikely that the photo targets rose more slowly than the mound beneath them, because, being hollow, their inertia was small. (In fact they were merely tossed aside undamaged.) Selected frames from the surface-motion film are reproduced in Appendix B. Information given below was obtained from a profile of the mound surface rather than from motion of the targets.

Figure 12 illustrates mound profiles as a function of time. It is clear that mound growth was quite symmetrical about the axis of the row of charges.

Vertical displacement, velocity, and acceleration are given as functions of time in Figures 13-15. The information is included for the record even though no data are available from directly comparable row-charge shots in level terrain. Other comparisons can be made, however. These charges at a scaled burial depth of 1.75 ft/lb$^{1/3}$ had an initial peak velocity of about 90 ft/sec. When scaled to 64 pounds, the vertical displacement-time of the surface over a single 256-pound charge at 1.5 ft/lb$^{1/3}$ in alluvium, as well as one in playa, agrees precisely for the first 12 msec with that of the 64-pound row charge at 1.75 ft/lb$^{1/3}$.[6] Photographs show that initially, surface motion over the charge is ahead of that between charges. The faster rate of displacement after 12 msec is probably the enhancement resulting from charge interaction within the row. Agreement during the first 12 msec suggests that the slightly

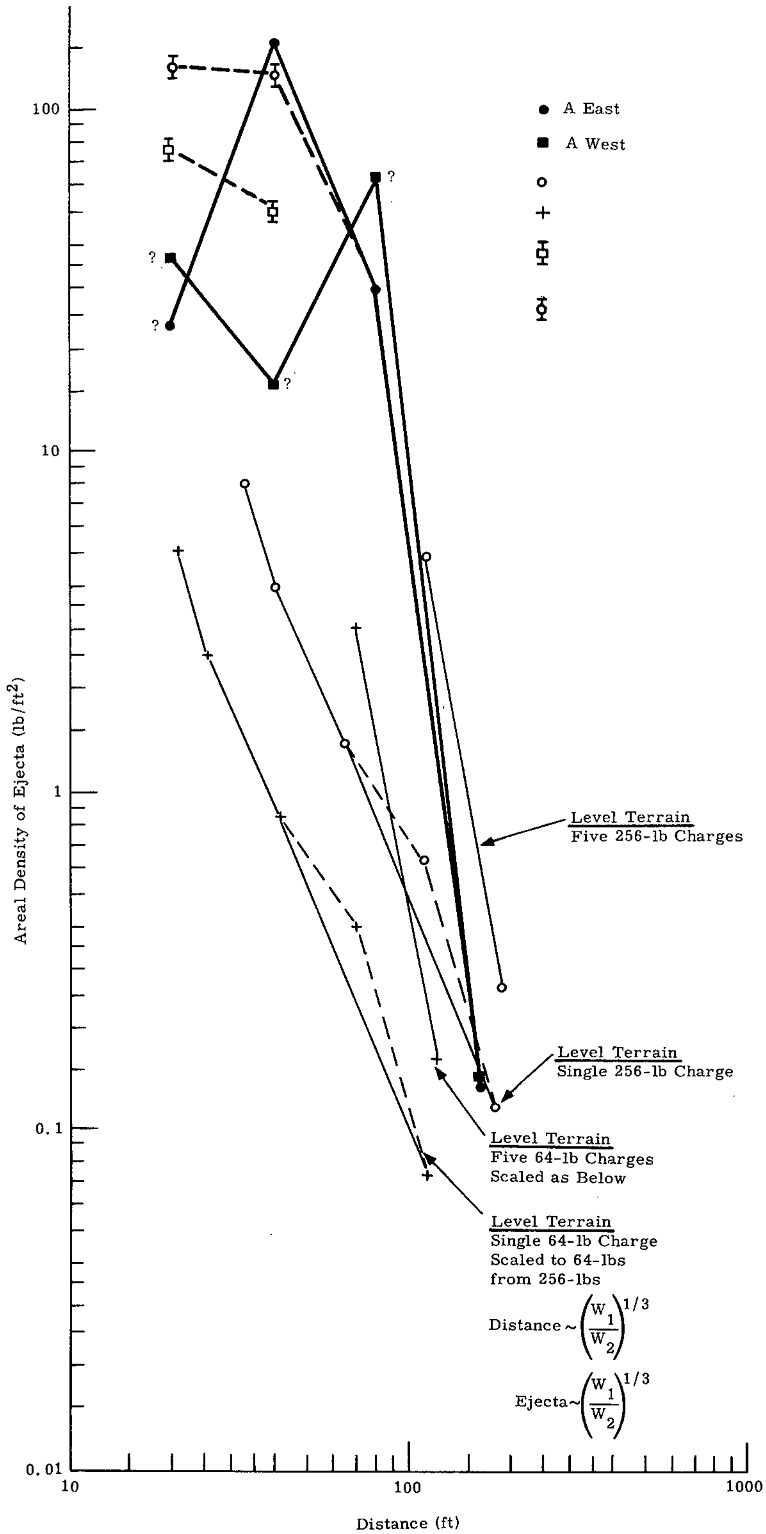


Figure 8. Areal density of ejecta versus distance perpendicular to center of row

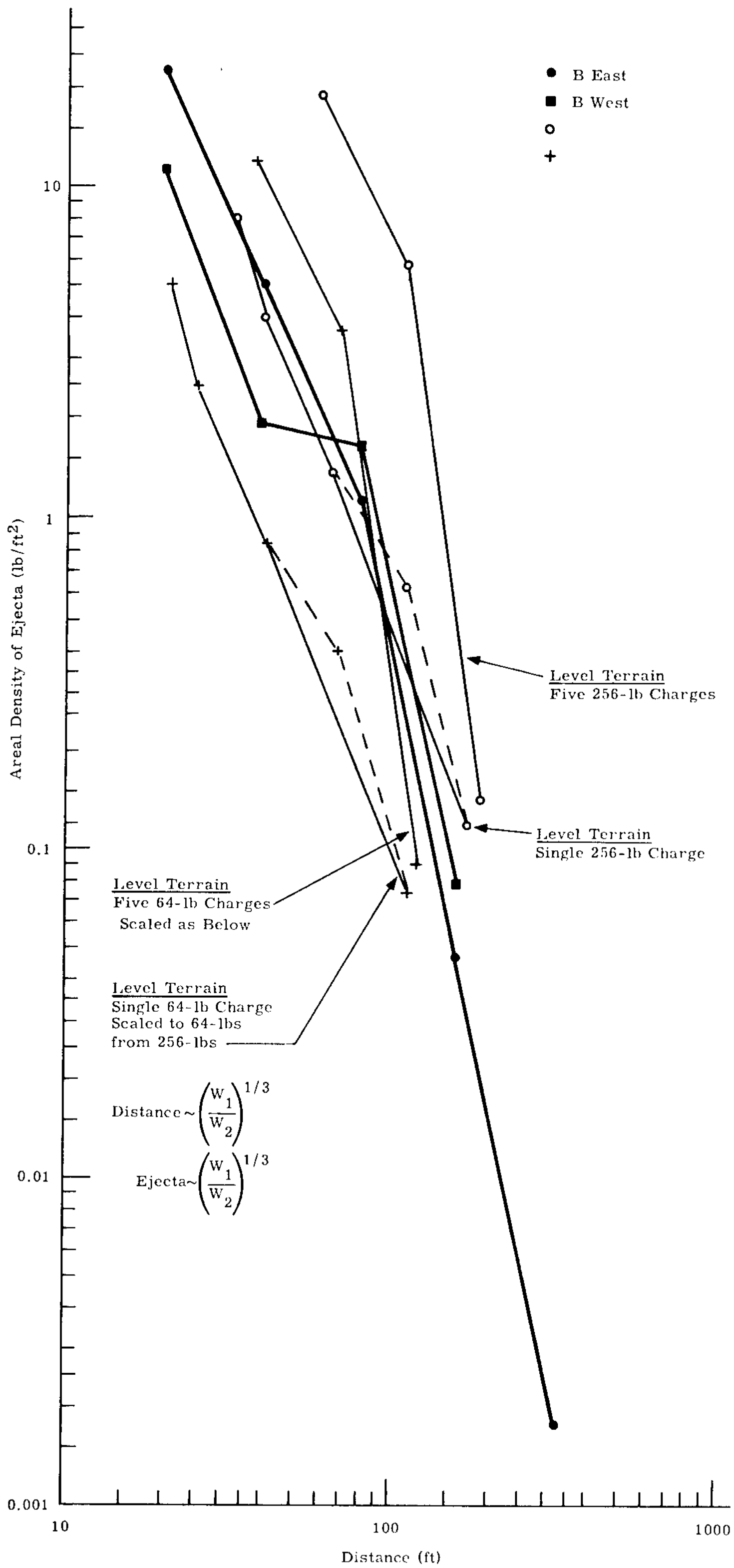


Figure 9. Areal density of ejecta versus distance perpendicular to the row at the end charge

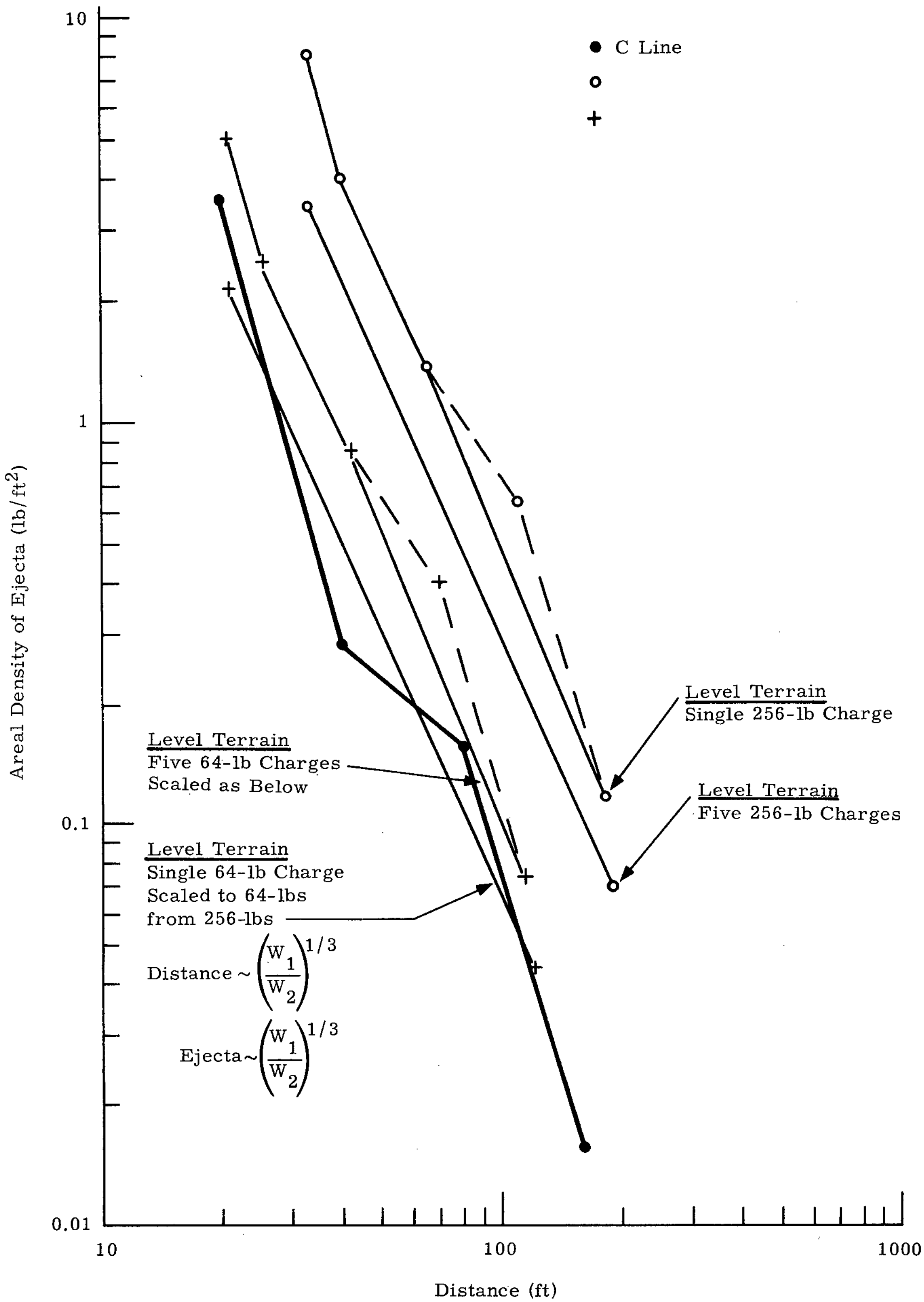


Figure 10. Areal density of ejecta vs distance at 45° angle from end charge

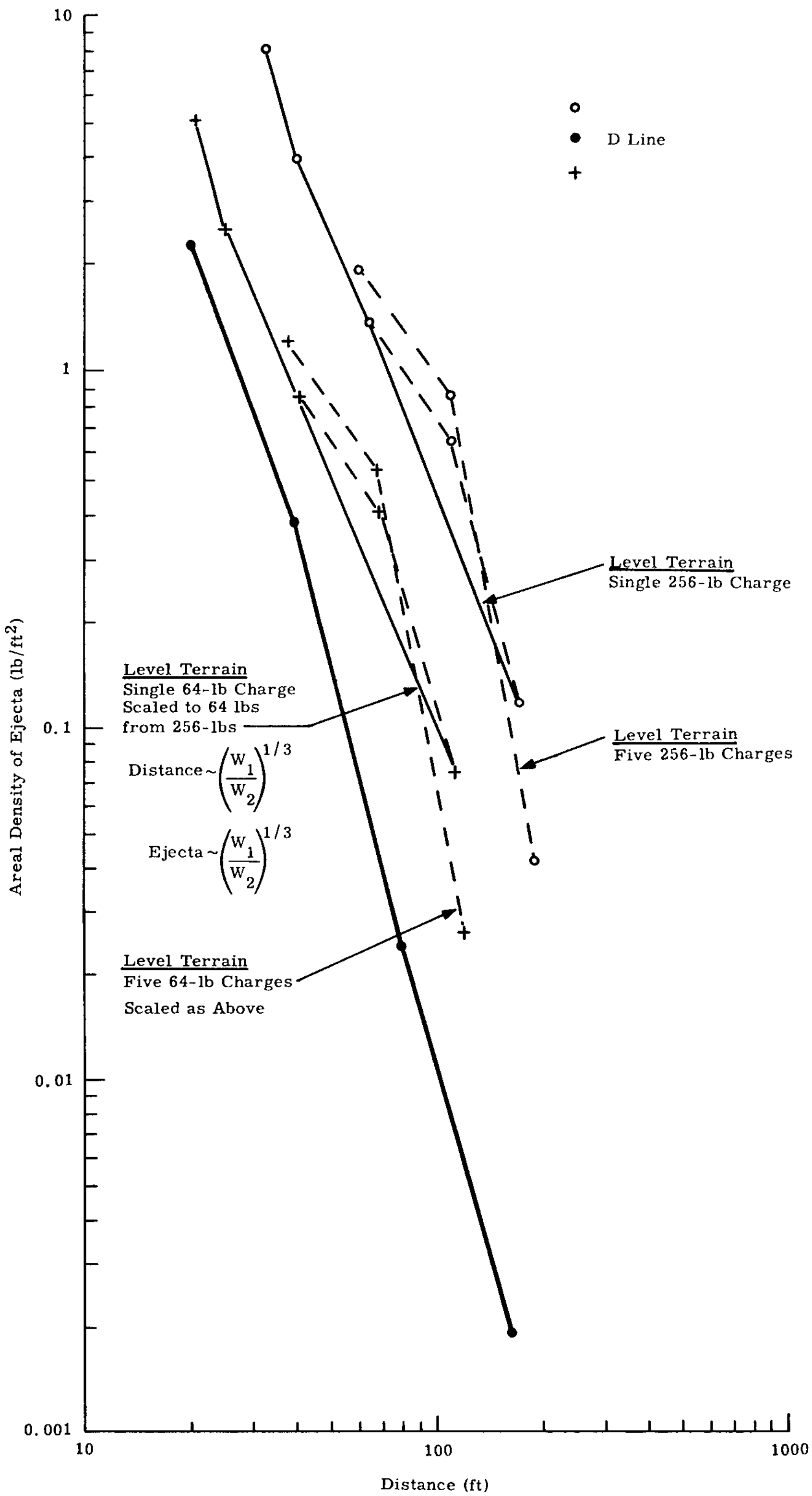


Figure 11. Areal density versus distance at end of row

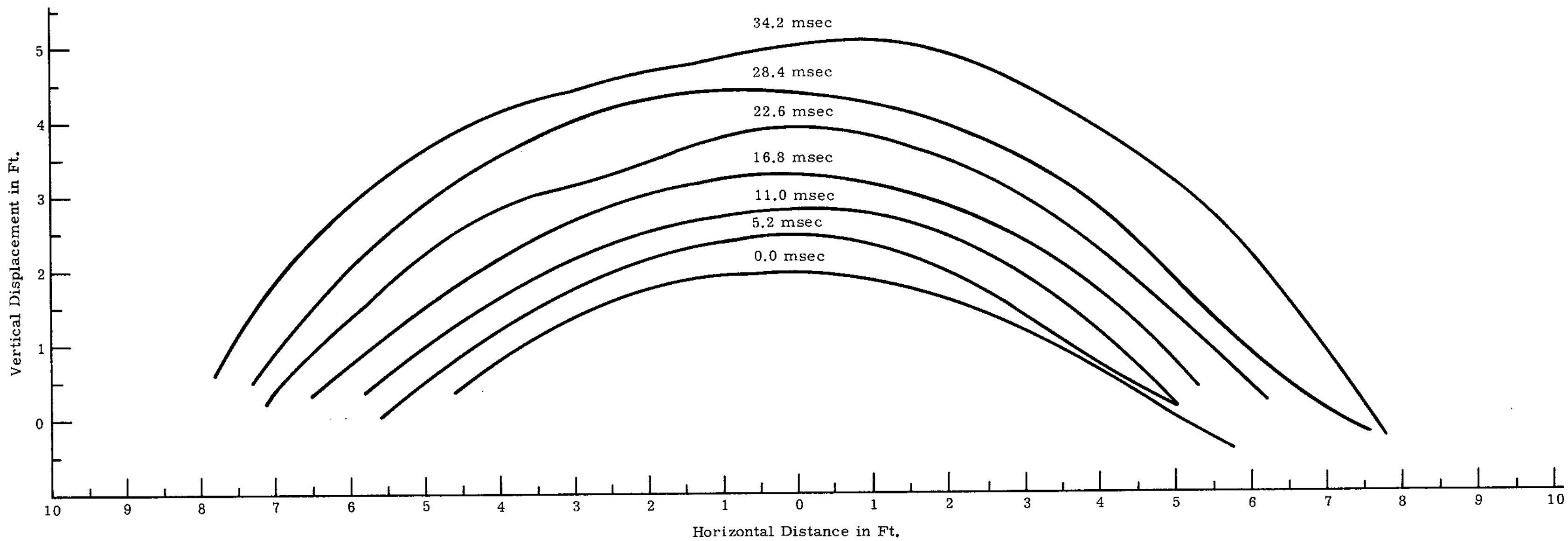
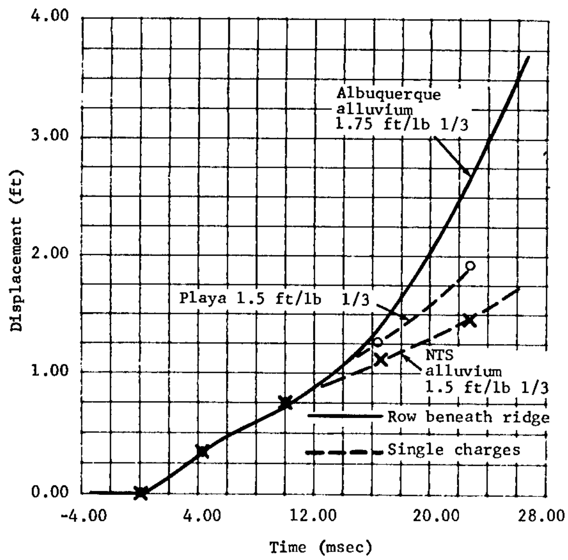
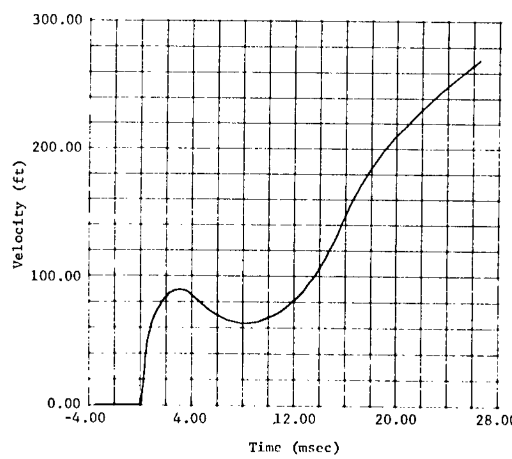


Figure 13. Mound profiles as functions of time



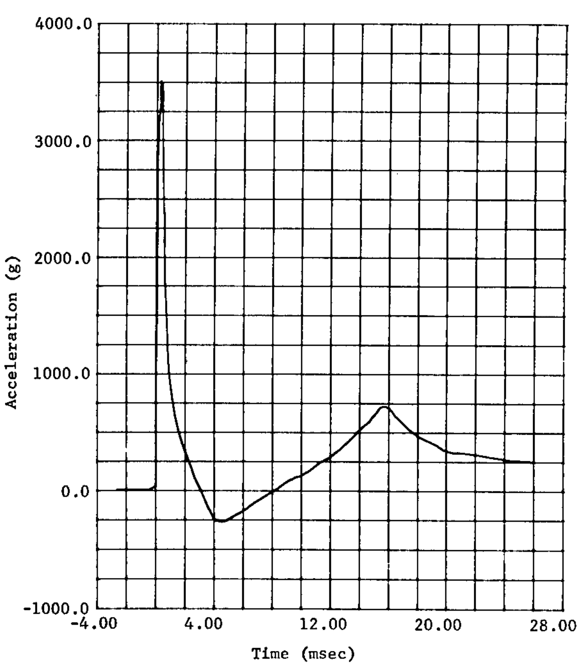
Test earth dam
Carrier 01

Figure 13.
Vertical displacement versus time



Test earth dam Carrier 01
Velocity data

Figure 14.
Velocity versus time



Test earth dam Carrier 01
Acceleration data

Figure 15.
Acceleration versus time

greater burial depth beneath the ridge compensates for the greater restraint offered by level terrain.

References

1. Pokrovski, G. I., Theory and Practice of Dam Construction by Directed Explosions, UCRL-Trans-1035(L), Moscow 1951.

2. Vesic, Aleksander, Phenomenology of Crater Formation, University of Georgia, Unreported work for Nuclear Cratering Group.

3. Vortman, L. J., A Small-Scale Investigation of the Possibility of Constructing Low-Relief Earth-Fill Dams Using Nuclear Explosives, SC-RR-65-41, Sandia Corporation, Albuquerque, New Mexico, February 1965.

4. Vortman, L. J., Comparison of Craters from Rows of Charges Detonated Simultaneously and One at a Time, SC-RR-67-728, Sandia Corporation, Albuquerque, New Mexico, November 1967.

5. Vortman, L. J., Craters from Short-Row Charges and Their Interaction with Pre-existing Craters, SC-1212-64-324, Sandia Corporation, Albuquerque, New Mexico, July 1966.

6. Vortman, L. J., Surface Motion Photography, Project Air Vent, SC-RR-67-1703, Sandia Corporation, Albuquerque, New Mexico, March 1965.

APPENDIX A

Selected Motion-Picture Frames Showing Ejecta Motion
(All frames except A-9 were taken at 136 frames per second)

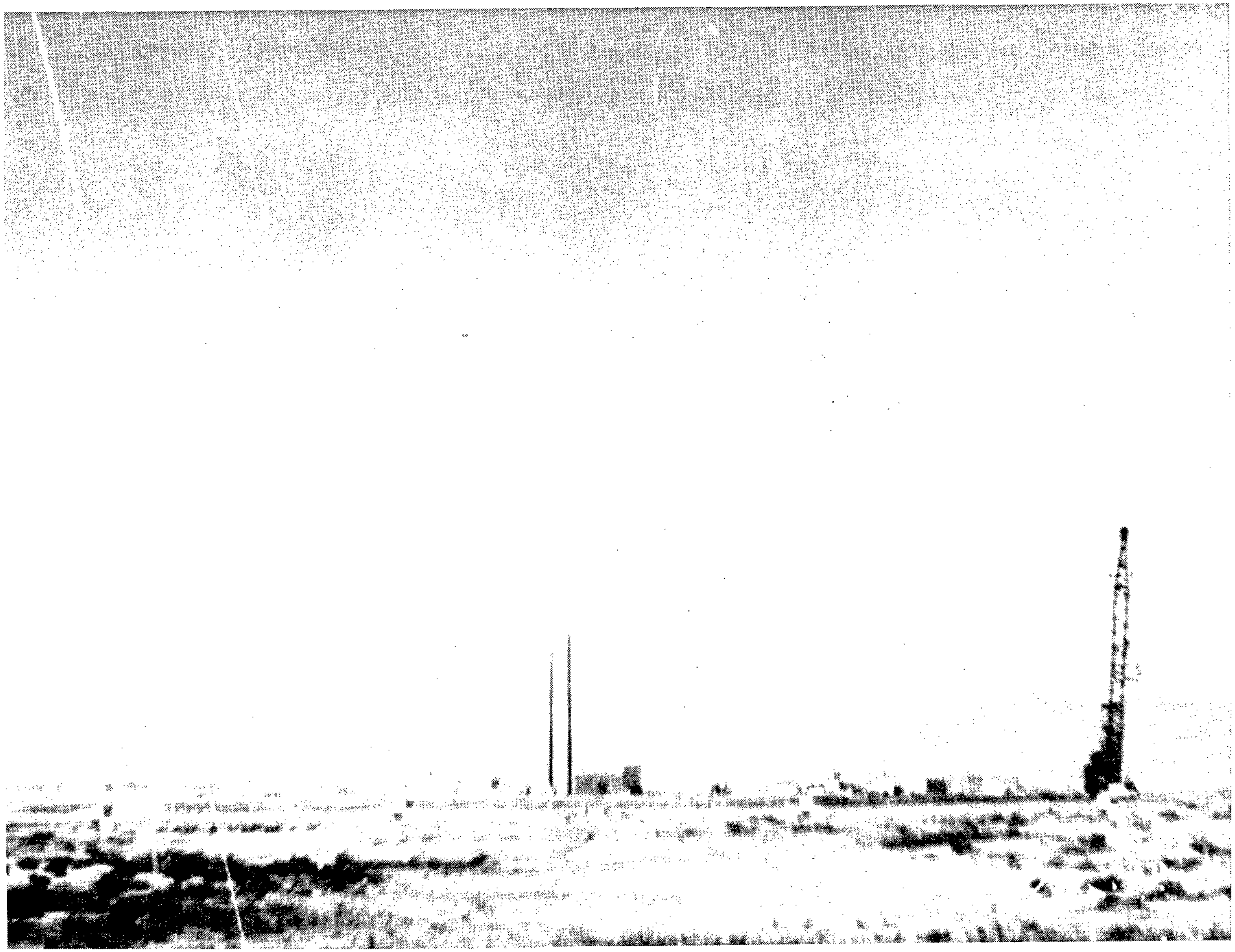
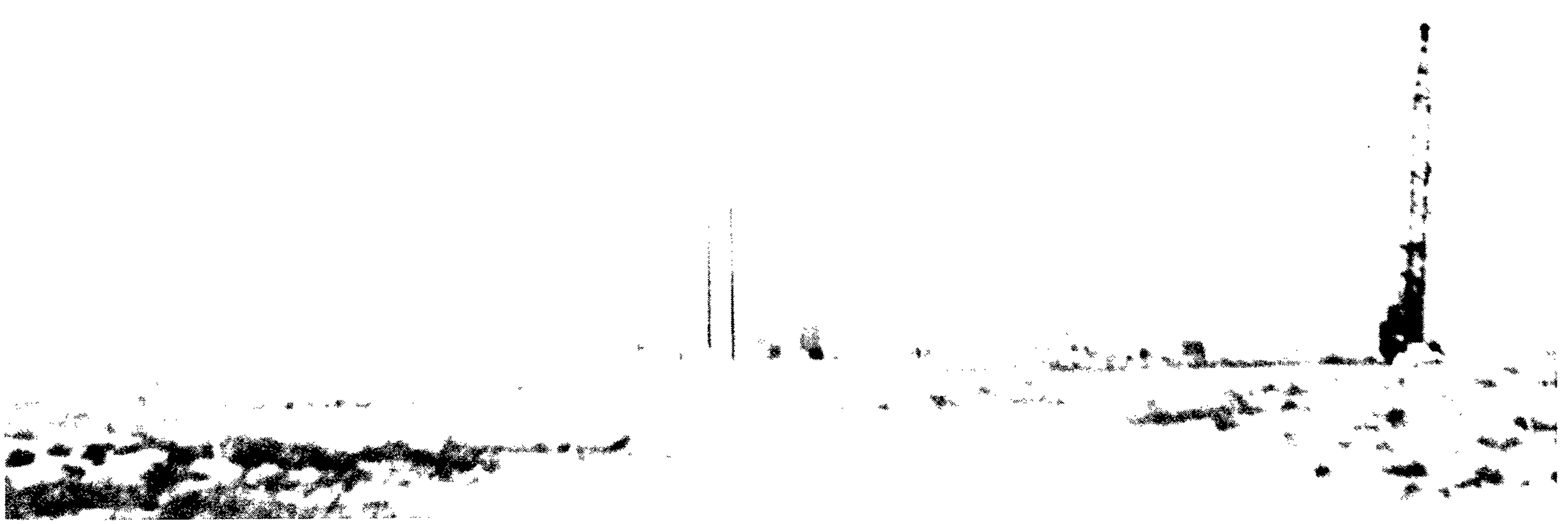
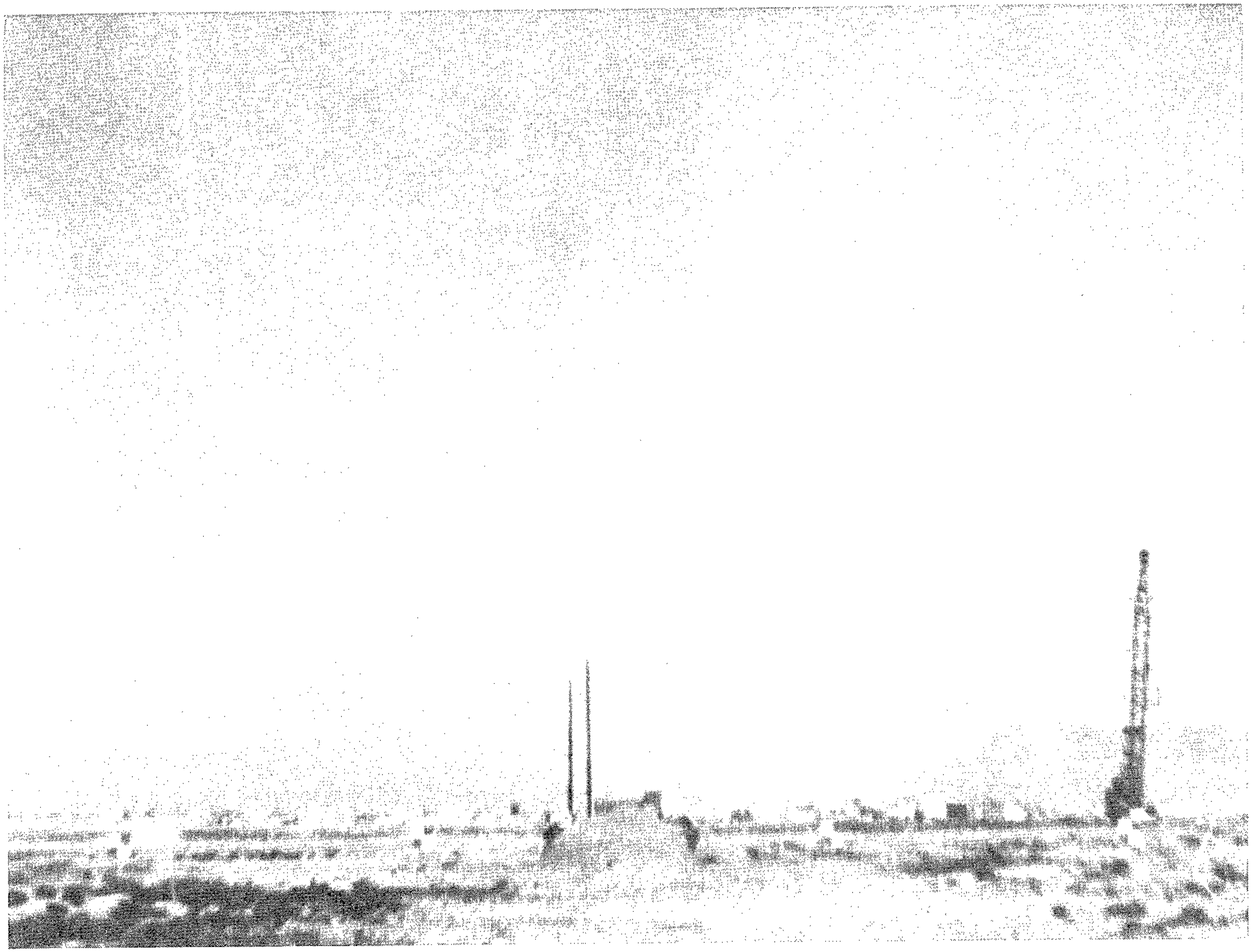


Figure A-1. O-time



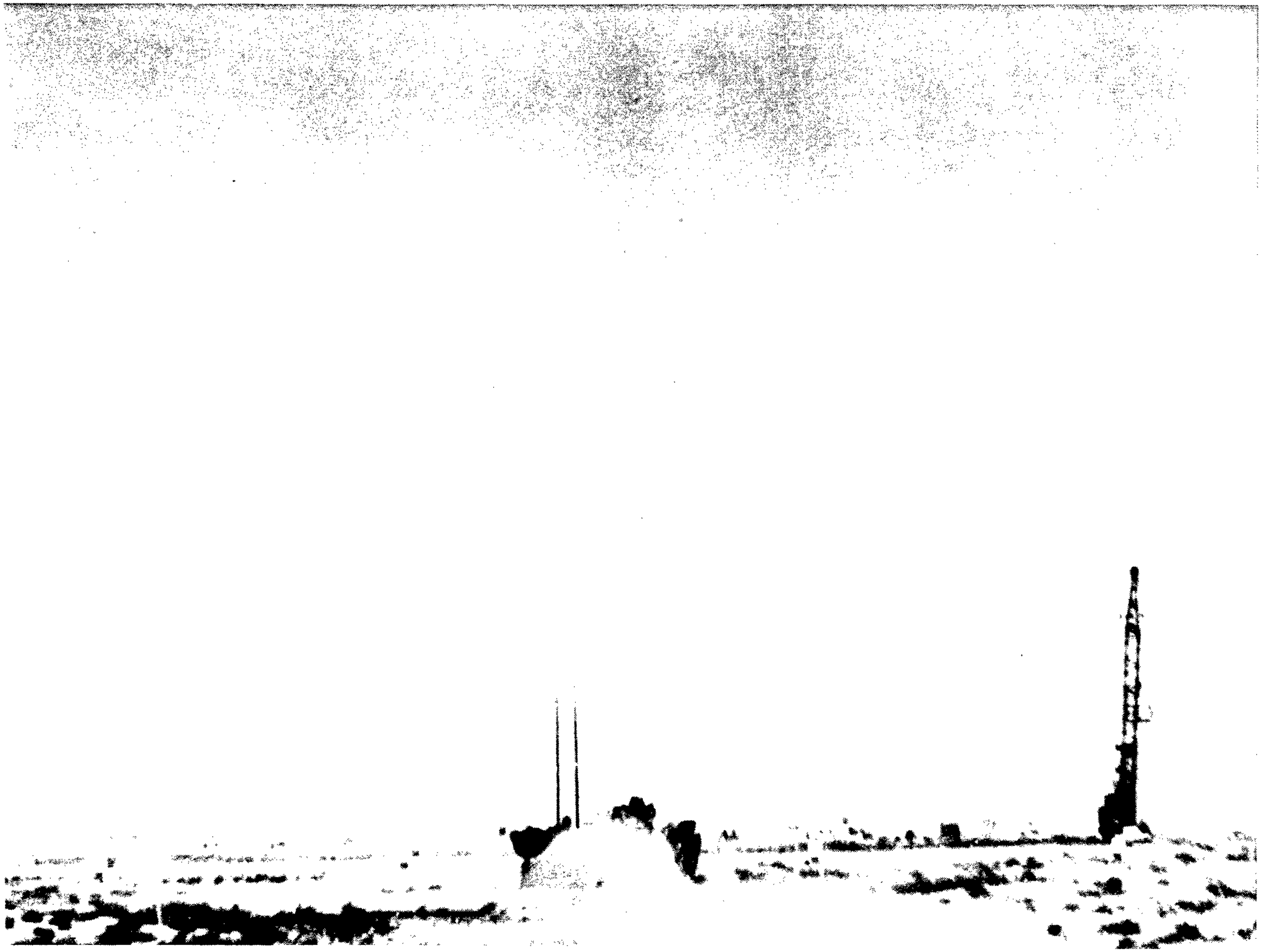
136 fps Frame #5 0 + 0.037

Figure A-2



Frame #10 0 + 0.074

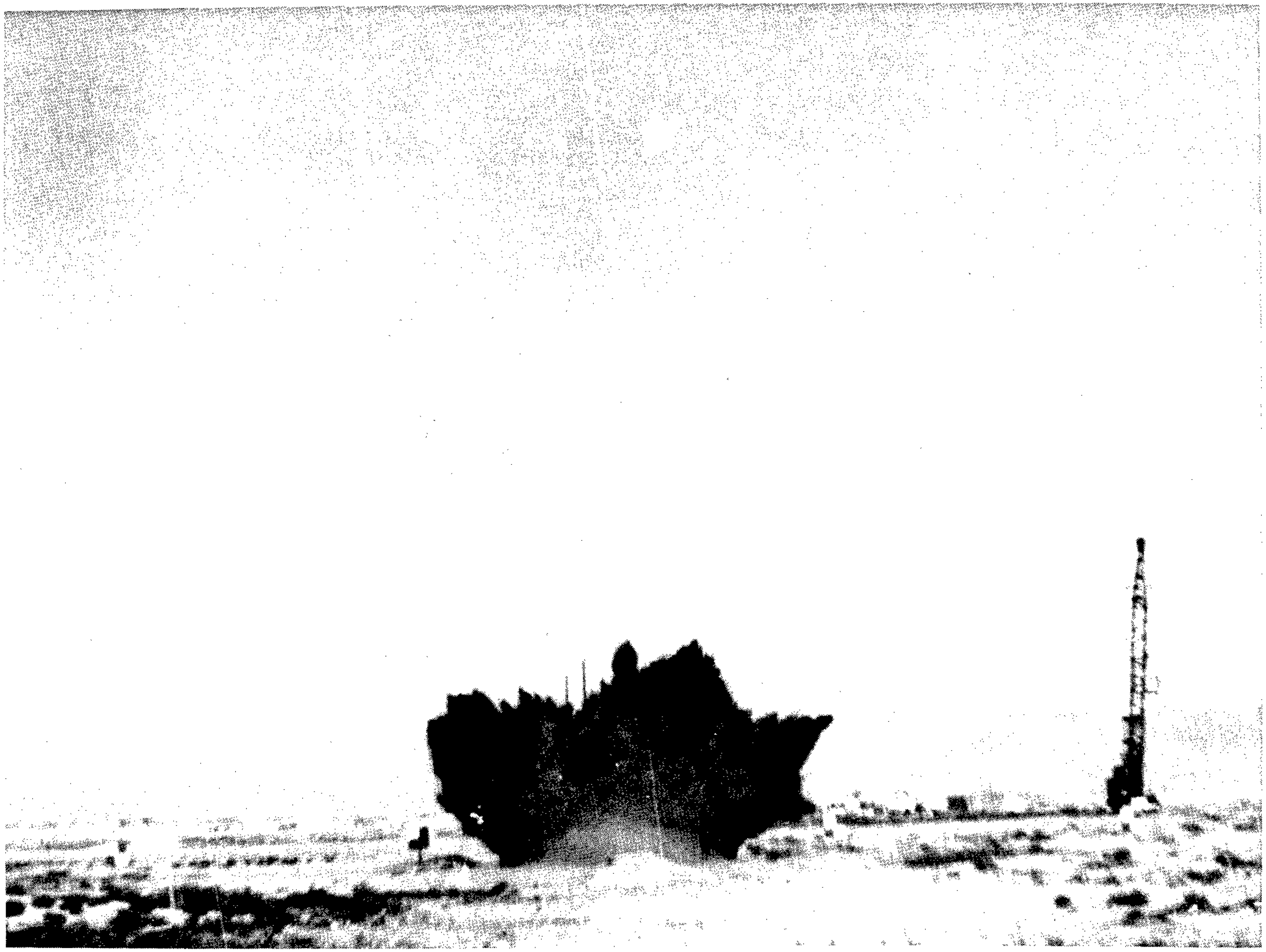
Figure A-3



Frame #20

0 + 0.147

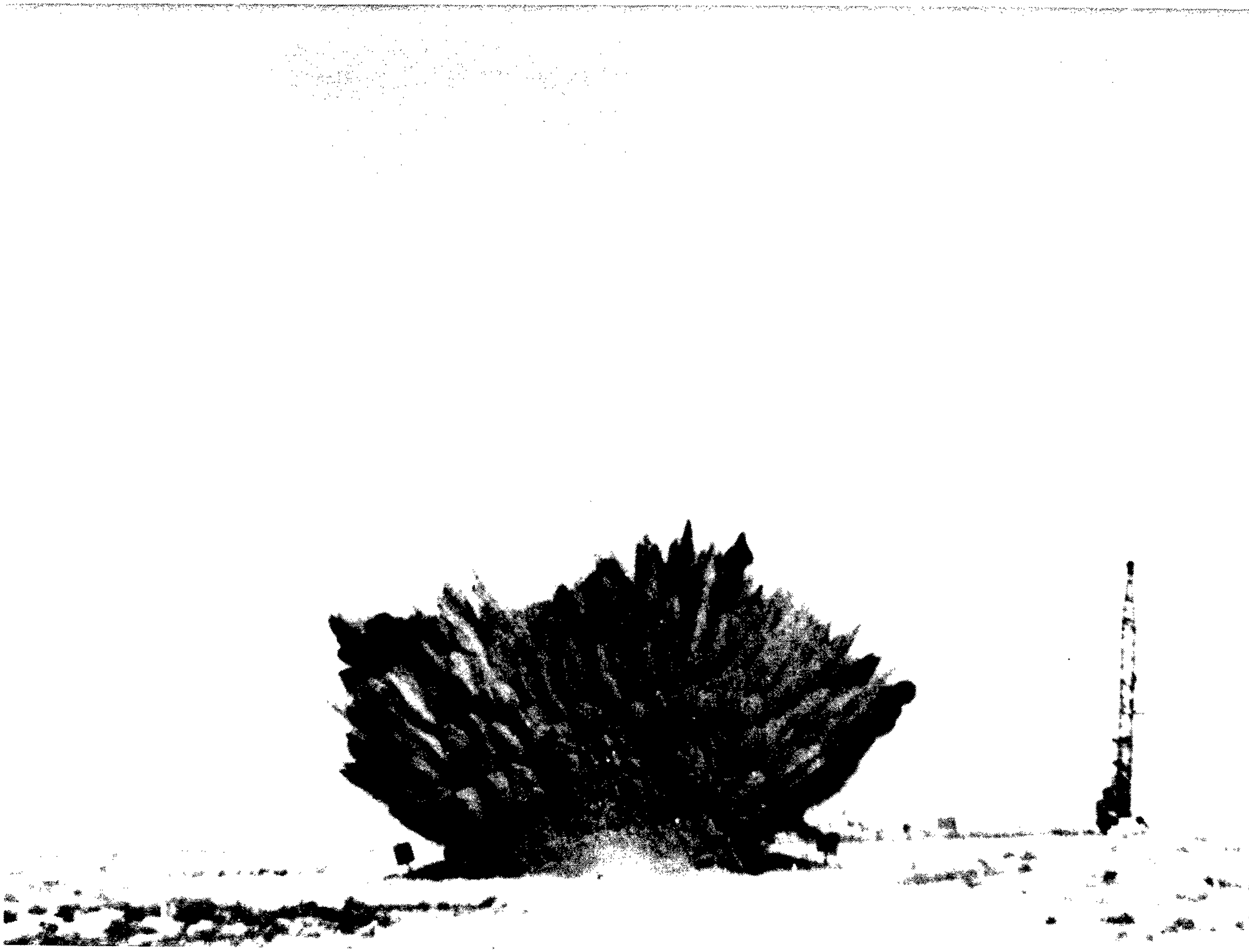
Figure A-4



0 + 0.294

Frame #40

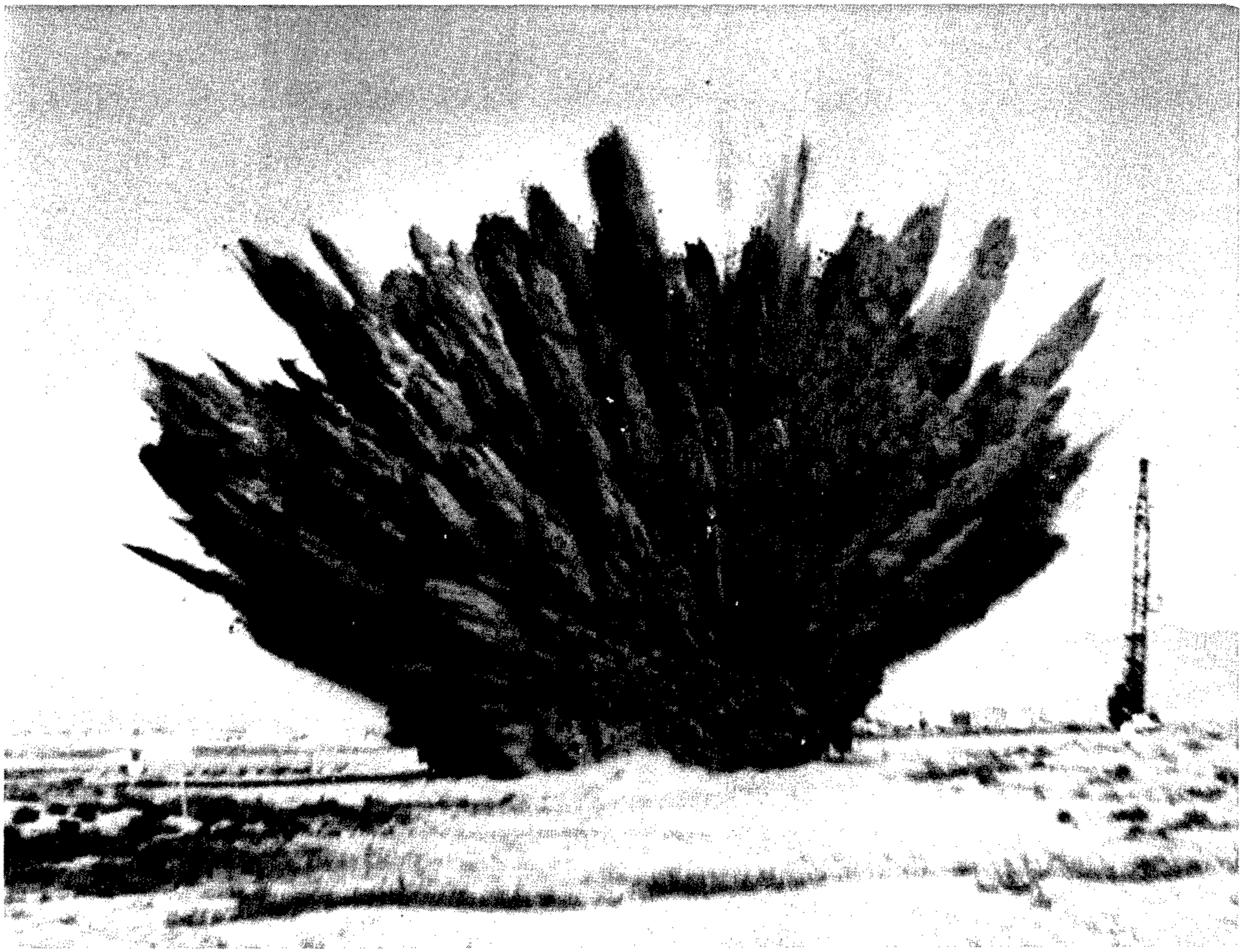
Figure A-5



Frame #80

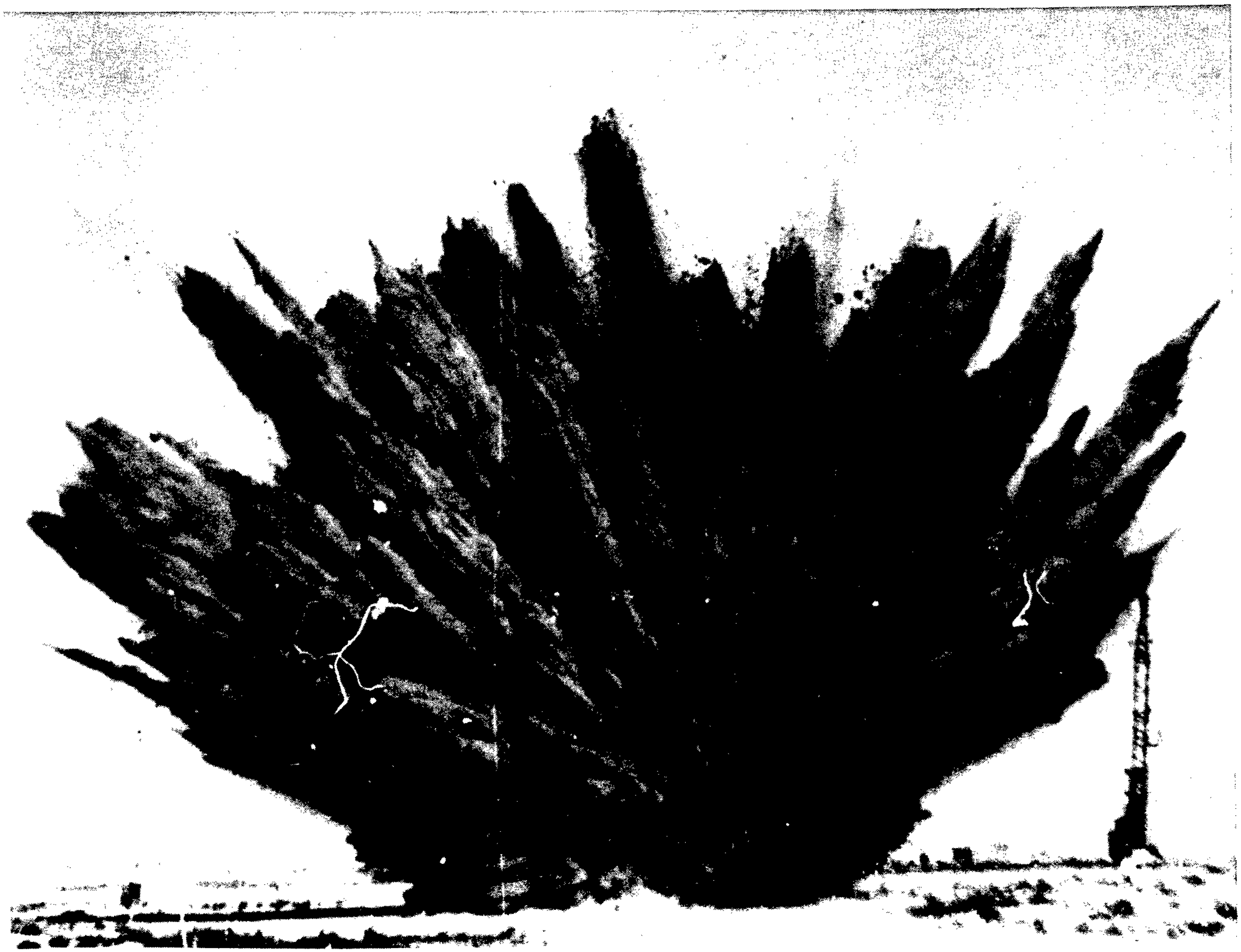
0 + 0.588

Figure A-6



Frame #160 0 + 1.180

Figure A-7



Frame #320 0 + 2.360

Figure A-8

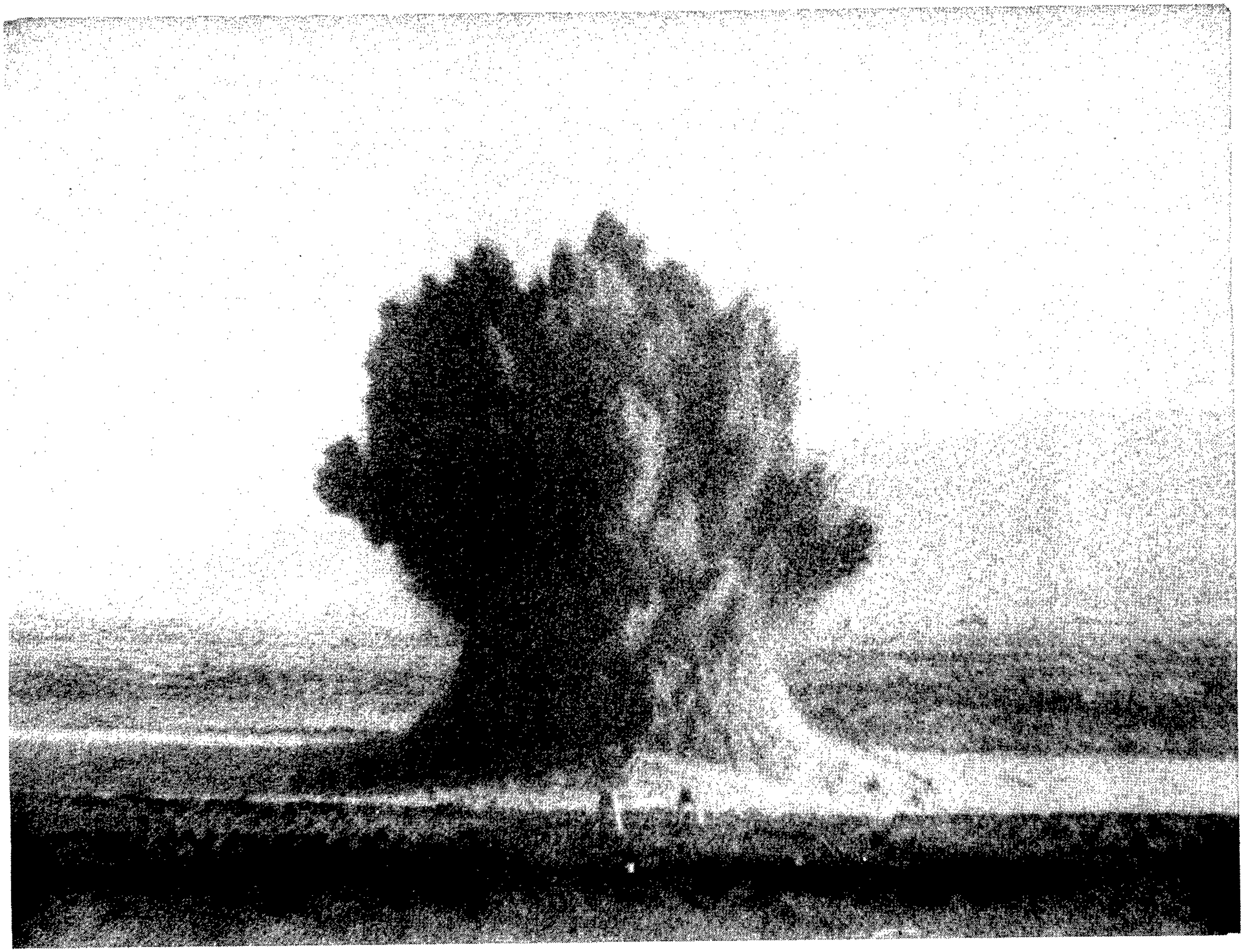
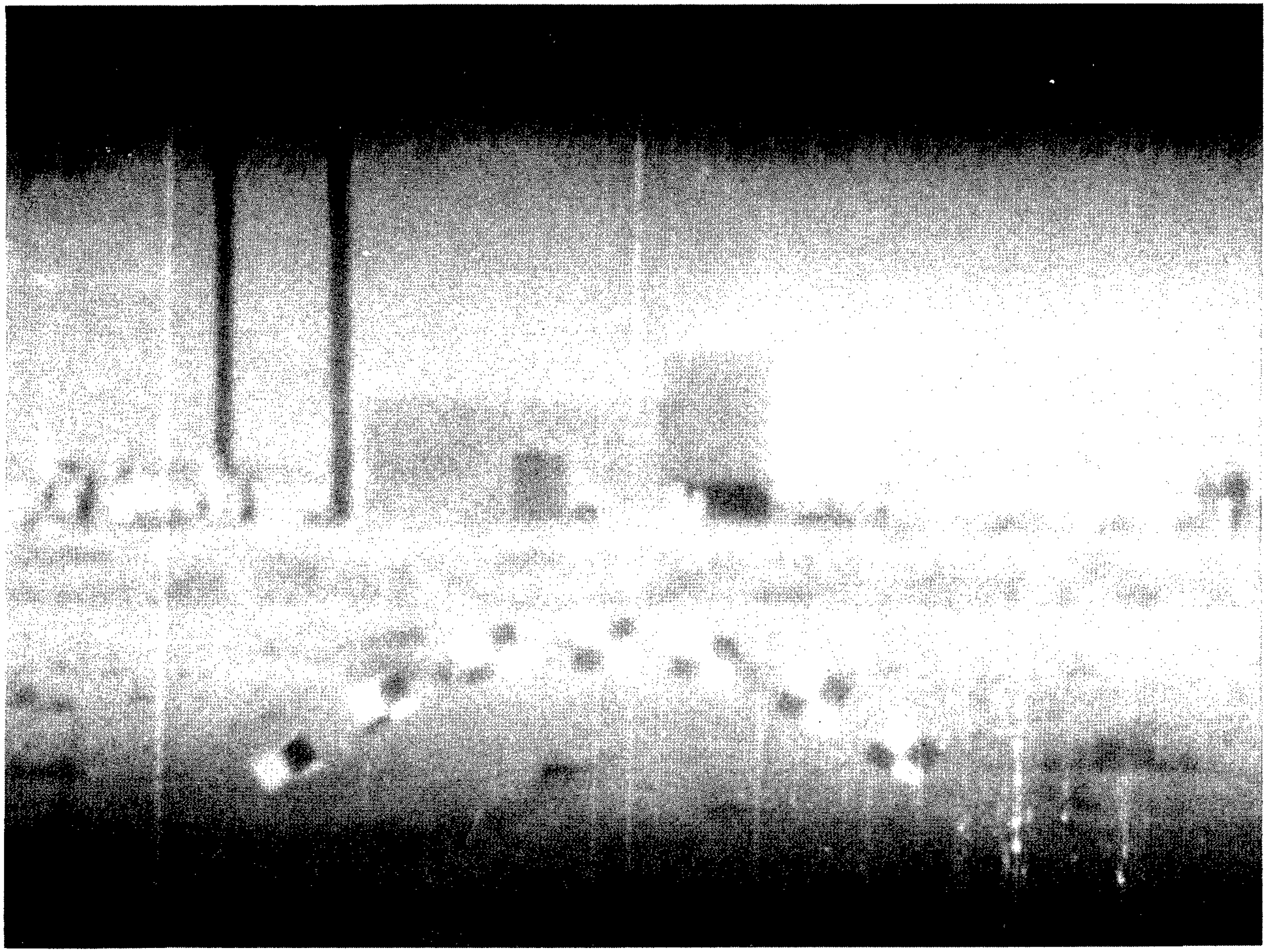


Figure A-9

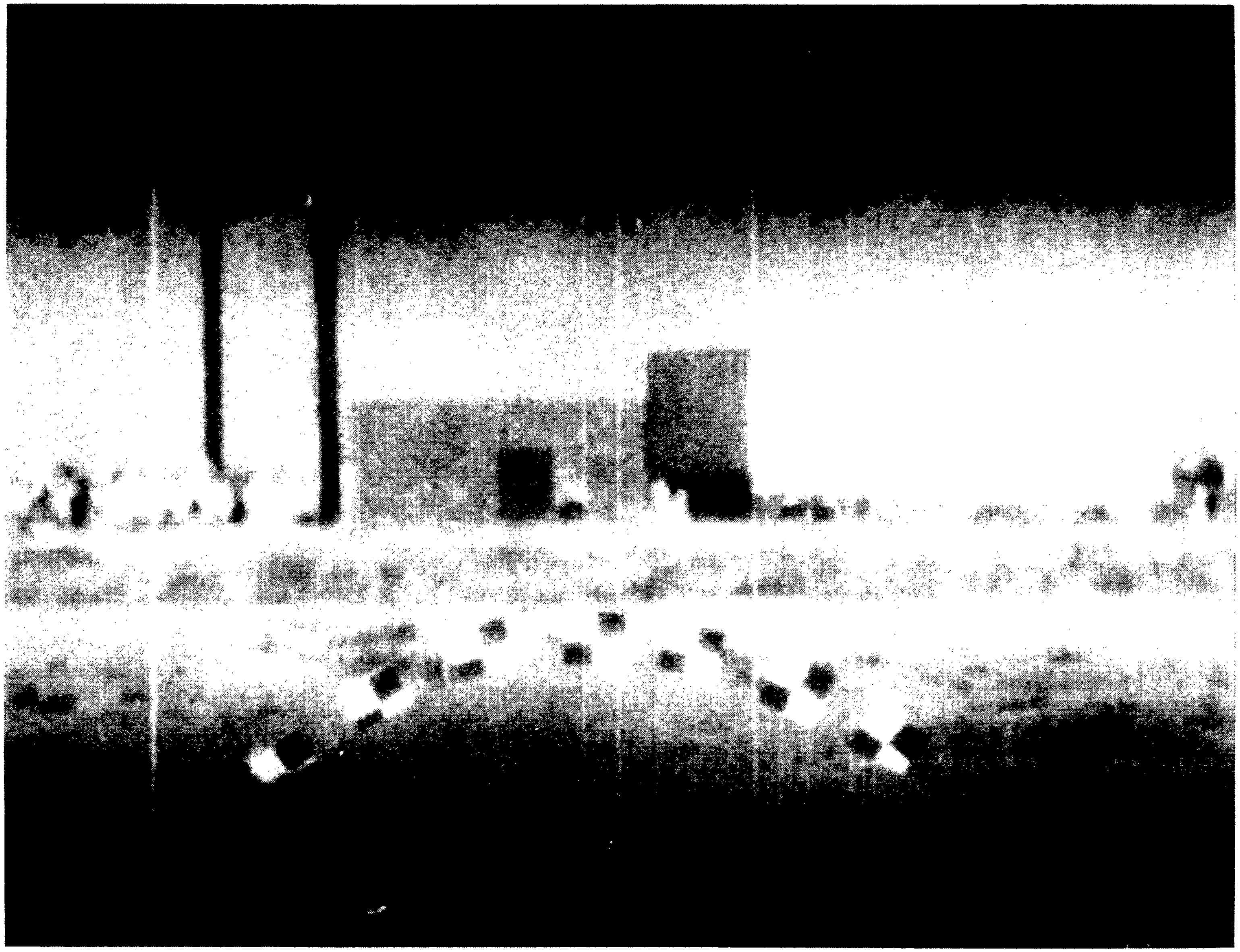
APPENDIX B

Selected Motion-Picture Frames Showing Surface Motion
(Film speed: 4900 frames per second)



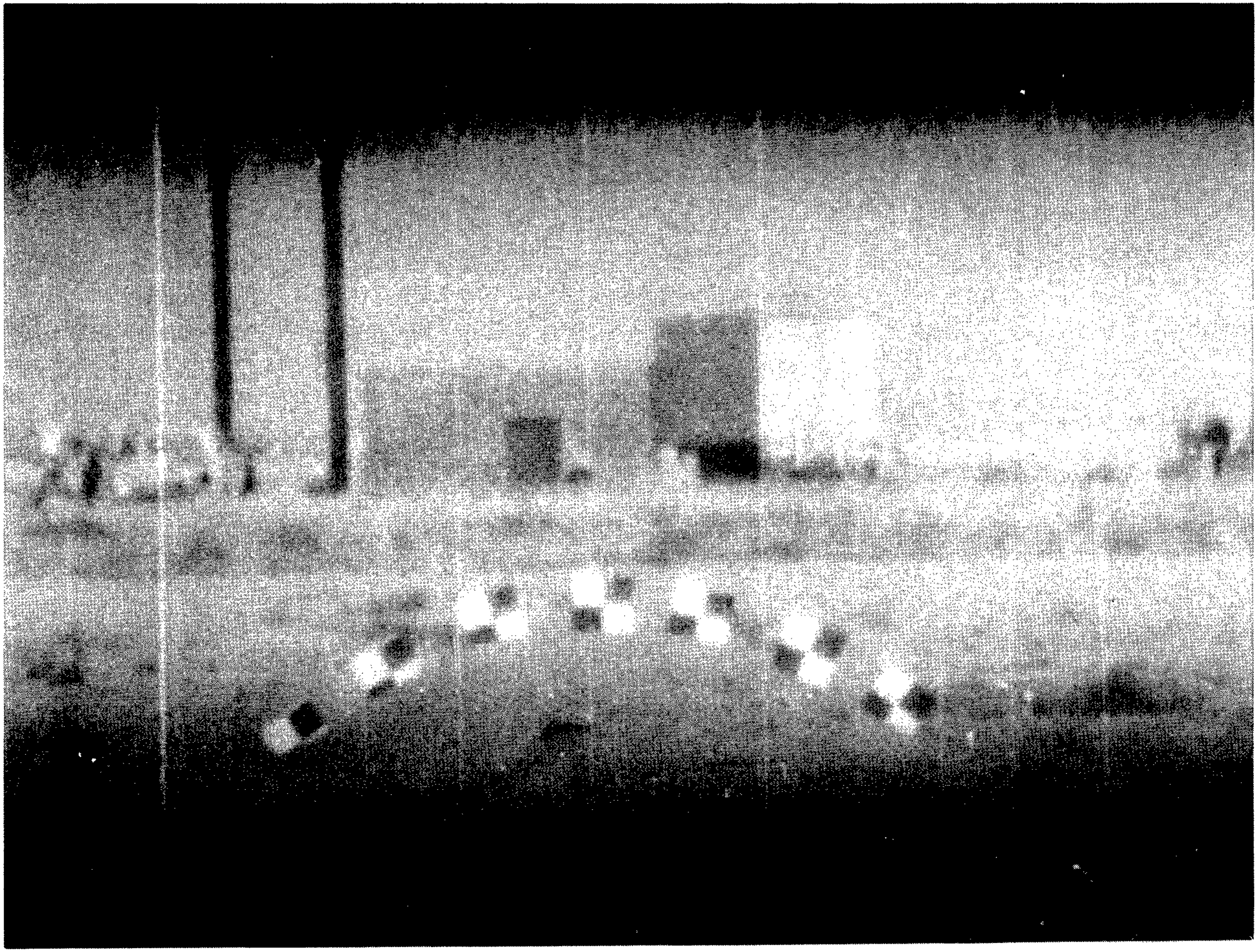
0 Time

Figure B-1



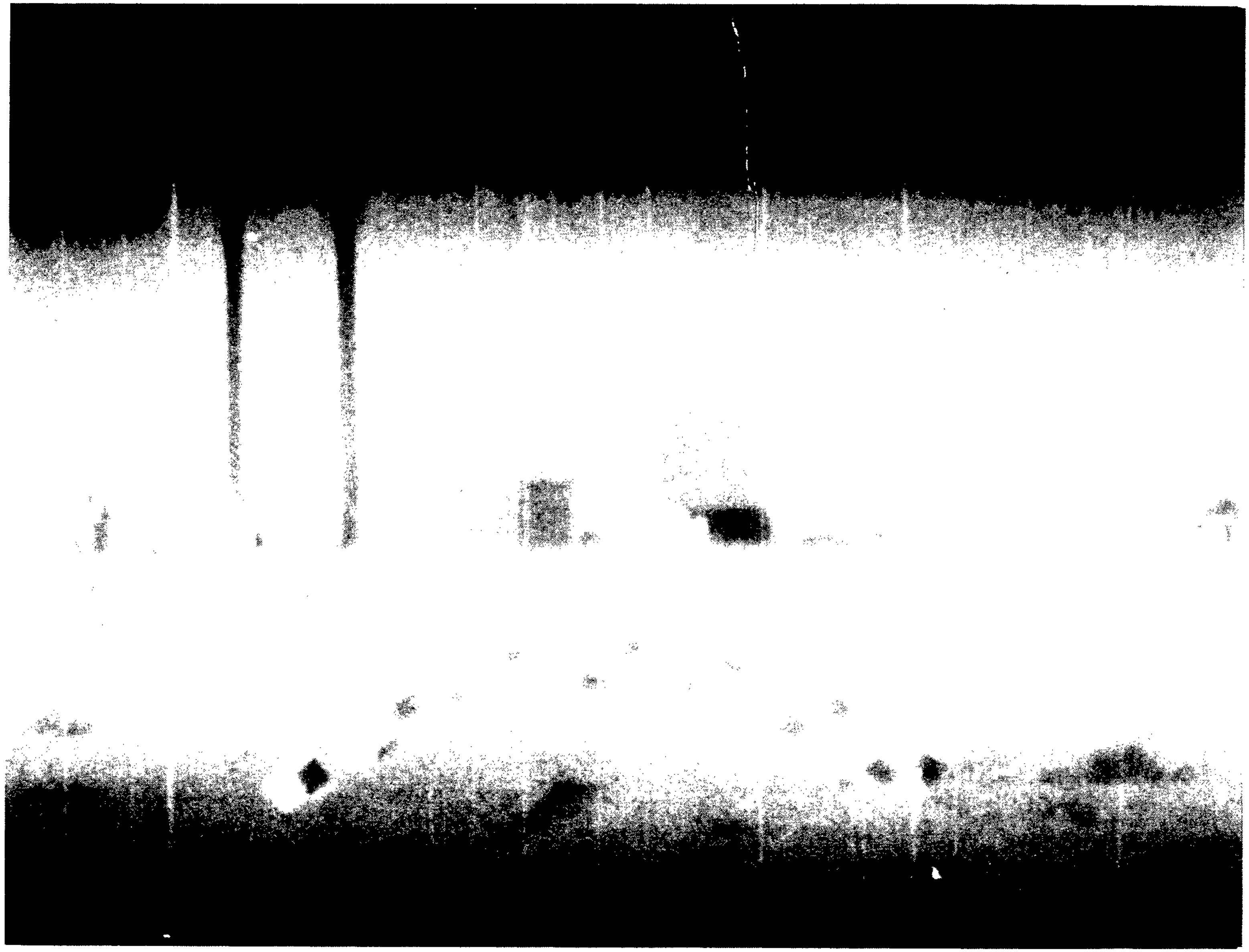
0 + 0.001 sec

Figure B-2



0 + 0.002 sec

Figure B-3



0 + 0.004 sec

Figure B-4

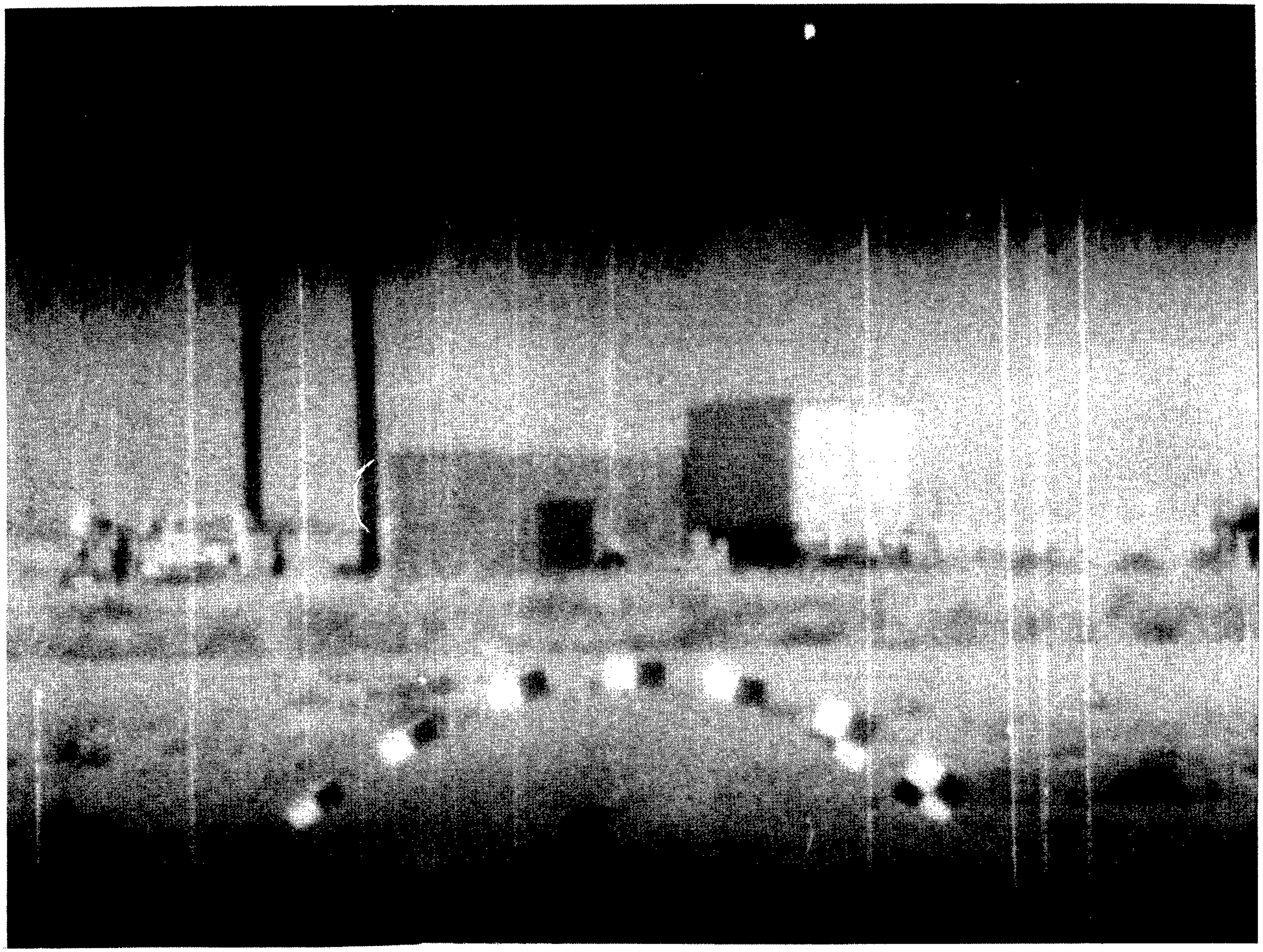


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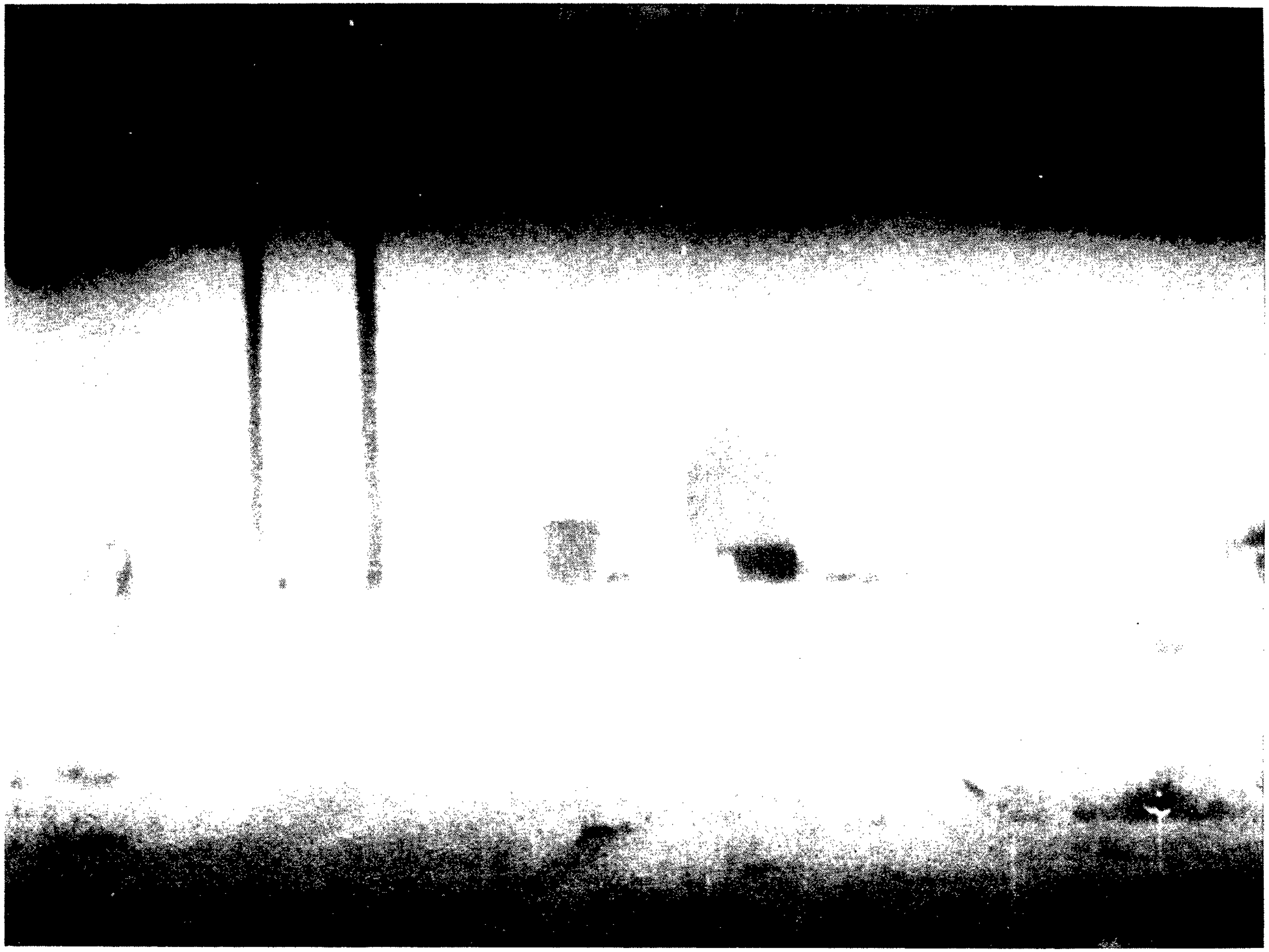
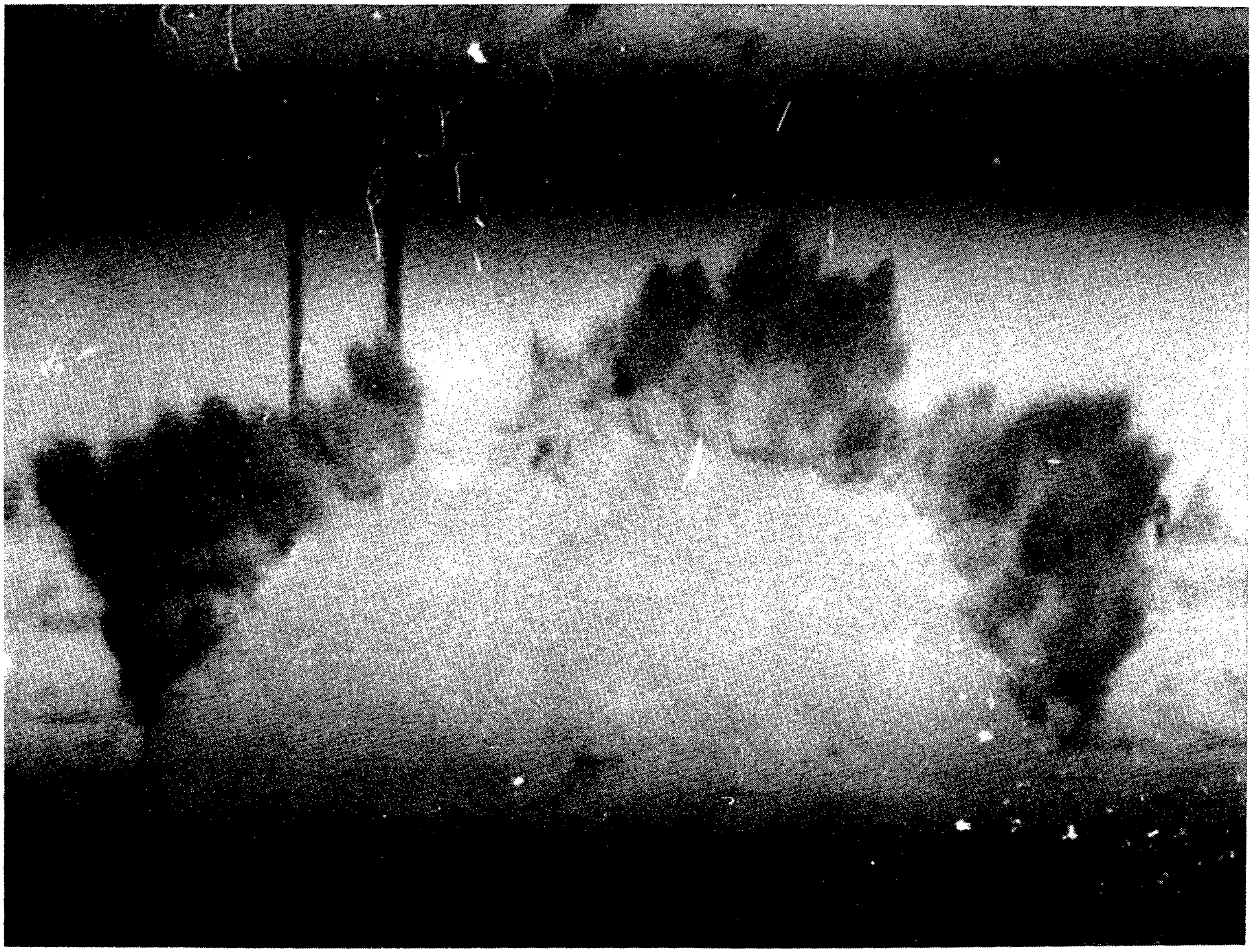
Figure B-5



0 + 0.016 sec

Figure B-6



0 + 0.032 sec

Figure B-7

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